

**ATLANTIC PACKAGING LTD. PAPER FIBRE BIOSOLIDS AND
SOUND-SORB BERM, OSHAWA SKEET AND GUN CLUB:
RESULTS OF CHEMICAL AND MICROBIOLOGICAL TESTING**

**Central Region
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EXECUTIVE SUMMARY

This report summarizes the findings of the chemical and microbiological analysis of:

1. paper fibre biosolids generated by the Whitby paper recycling mill owned by Atlantic Packaging Ltd. and
2. Sound-Sorb, a product, comprised of an approximate 70:30 mixture of paper fibre biosolids to screened mineral soil.

Paper fibre biosolids have been spread on agricultural land since 1991 under a Certificate of Approval issued to Atlantic Packaging Ltd. and Courtice Auto Wreckers Ltd. for an organic waste management system. Sound-Sorb is produced by Courtice Auto Wreckers Ltd. and is currently being used to construct sound and bullet attenuation berms at gun clubs in Ontario. Through the mixing of paper fibre biosolids with mineral soil, Sound-Sorb is exempt from the Ministry of Environment and Energy's waste management regulations and the Environmental Protection Act. Considerable concern has been raised by the public regarding the possible environmental effects of the land application of paper fibre biosolids and the use of Sound-Sorb. In response, the ministry is currently reviewing both the land application of paper fibre biosolids and the management of Sound-Sorb. The data provided in this report will contribute to the information used for deciding on the next steps in this review.

Samples were taken from the Whitby mill of Atlantic Packaging and from the Sound-Sorb berm at the Oshawa Skeet and Gun Club in the Regional Municipality of Durham. Samples were analyzed for a large variety of inorganic and organic elements and compounds. Results for fresh Atlantic Packaging Ltd. paper fibre biosolids were compared to the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land*. For parameters for which there are no biosolids standards, results were compared to the typical range of background for uncontaminated soils in Ontario. Microbiology results for both fresh paper fibre biosolids and Sound-Sorb were compared to the United States Environmental Protection Agency guidelines for fecal coliform in biosolids used for application to agricultural land. Results for Sound-Sorb were compared to remediation guidelines outlined in the *Guidelines for Use at Contaminated Sites in Ontario*.

Fresh Paper Fibre Biosolids

The fresh paper fibre biosolids met all guideline levels in the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land*. These guidelines include arsenic, cadmium, cobalt, chromium, copper, mercury, molybdenum, nickel, lead, selenium, zinc, pH, phosphorus and sodium. The fresh paper fibre biosolids were lower in fecal coliform indicator bacteria (*E. coli*) than the United States Environmental Protection Agency fecal coliform guideline for Class B biosolids. Published literature has shown that the *E. coli* present in pulp and paper waste is non-pathogenic. There are no biosolids guidelines for the volatile organic compounds toluene, xylenes, and ethylbenzene. Although low, the concentrations of these compounds in fresh paper fibre exceeded the typical concentration range of these compounds in uncontaminated background soil in Ontario.

Sound-Sorb

With the exception of total petroleum hydrocarbons, concentrations of all elements and compounds measured in the Sound-Sorb berm at the Oshawa Skeet and Gun Club were lower than the Table A remediation guidelines outlined in the *Guidelines for Use at Contaminated Sites in Ontario*. Moreover, for all but toluene and free cyanide, the concentrations of elements and compounds measured in the Sound-Sorb berm were lower than the typical range of background soils in Ontario. Fecal coliform indicator bacteria were not detected in the berm samples.

Conclusions and Recommendations

In the absence of biosolids guidelines and because toluene, xylenes and ethylbenzene were higher than the typical range of uncontaminated soil in Ontario, volatile organic compound testing on the soil and groundwater at sites receiving paper fibre biosolid application is recommended. The measurement of total petroleum hydrocarbons and free cyanide on the fresh biosolids is also recommended to provide further information on this material, as these compounds were only measured in Sound-Sorb. Given the total concentration of elements and compounds in the fresh paper fibre biosolids, it is unlikely that Regulation 347 toxicity characteristics leachate standards would be exceeded. Nevertheless, the toxicity characteristic leachate procedure should also be included in further work on the biosolids.

To assess the movement of chemicals through the berm, groundwater and surface water monitoring for a full suite of chemical parameters is recommended. Although *E. Coli* bacteria were not detected in the Sound-Sorb berm and although published evidence shows that fecal coliform indicator bacteria in pulp and paper waste are non-pathogenic, their presence in fresh paper fibre biosolids make it important to also measure fecal coliform bacteria in the Oshawa Skeet and Gun Club test wells. The Ministry is further pursuing the investigation of bacterial activity in paper fibre biosolids and Sound-Sorb through a contract to investigate the potential for and the generation of bioaerosols by the paper fibre biosolids.

While total petroleum hydrocarbons in the berm material exceeded the Table A, *Contaminated Site Guidelines*, these guidelines are intended for use on the soil on a site, not the foreign material deposited on top of the soil. For this reason a site specific risk assessment of the Oshawa Skeet and Gun Club berm is recommended to investigate the potential for movement of petroleum hydrocarbons through the berm.

INTRODUCTION

Atlantic Packaging operates two paper recycling plants in Ontario located in Scarborough and Whitby. The Scarborough mill recycles paper and cardboard to make paper towels, tissue paper and corrugated cardboard. The Whitby mill recycles magazines and newspapers to produce tissue paper and newsprint. The wastewater treatment system at each plant includes a primary clarifier tank and a secondary activated sludge tank for settling the solids. The solid material consists of a mixture of paper fibre, calcium/magnesium carbonate, kaolin clay and talc and is flocculated in the primary clarifier by the addition of flocculating agents. The primary and activated sludges are removed from the bottom of each clarifier tank, combined and de-watered to produce a paper fibre biosolid. The material consists of approximately 25% paper fibre, 25% clay and 50% water. This material is classified by the Ministry of the Environment and Energy as non-hazardous waste under Regulation 347. In the 1980s, consistent with the provincial government's focus on waste reduction and recycling, Atlantic Packaging began to explore the possibility of reuse and recycling of the paper fibre biosolids (PFB) which, until then, were wholly disposed of in landfill sites. Approximately 700 tonnes wet weight of paper sludge or 350 tonnes dry weight are generated each day by the two mills, seven days a week.

Spreading of Paper Fibre Biosolids on Agricultural Land

In 1991, the Ministry of the Environment (MOE) issued a Provisional Certificate of Approval (C of A) to Atlantic Packaging Products Ltd. for an organic waste management system. The C of A was issued jointly to Atlantic Packaging Products Ltd. and Courtice Auto Wreckers Ltd. to accommodate the spreading of paper fibre biosolids on agricultural land as a soil conditioner. This program diverted a portion of the paper fibre sludge from the landfill site to agricultural land. The program was initially approved by the Councils for the Townships of Brock and Scugog. By the end of 1991, over 80 farmers had enrolled in the program. Later, Clarington and Uxbridge townships approved PFB spreading and today 106 sites have been approved for the application of PFB in Durham Region. Prior to site approval, soil analysis data for the proposed fields must be submitted to the MOE. Once approved, PFBs can be spread at a rate of 30 tonnes (wet weight)/ha/yr for five years. Subsequent soil testing must be done if site approval is requested for another five years. At three of the sites, soil testing before and after application of the biosolids is carried out to ensure that metal levels fall at or below the concentrations stipulated in the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land (1996)*. Analysis of groundwater at the same three sites is also required under the C of A and analysis of surface water at two sites with appropriate surface drainage is required uphill and downhill from the sites. The surface water sites must be sampled every quarter when surface drainage is occurring. One set of samples must be representative of spring runoff conditions and one set must be representative of summer storm conditions. Testing requirements are outlined in the Certificate of Approval and are listed in Appendix III.

The Certificate of Approval also requires monthly, quarterly and semi-annual chemical testing of

the PFB material (Appendix III). Spreading restrictions related to site slope characteristics and set-back distances from homes, wells, water courses, and sensitive areas are identified in the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land (1996)*. The Certificate of Approval prohibits spreading of PFB on frozen ground. The original Provisional Certificate of Approval was issued for a one year period in 1991. From that time, temporary extensions to the Certificates of Approval and revised Certificates of Approval have been issued while studies have been conducted to determine the agricultural benefit of PFB application.

Since 1991, in fulfilment of the conditions of the Certificate of Approval, Atlantic Packaging has provided the MOE with annual reports which include monthly, quarterly and semi-annual chemistry data for the sludge produced by the Whitby and Scarborough mills, as well as soil, groundwater and surface water chemistry data for the three monitored sites upon which PFB has been applied. Between the years 1994 and 1998 an unaccredited laboratory was contracted by Atlantic Packaging Ltd. for testing the material. A laboratory intercomparison was undertaken in 1998 between the contract laboratory and the ministry laboratory. In 1999, the requirement to use an accredited laboratory was incorporated into the Certificate of Approval issued to Atlantic Packaging. Furthermore, because dioxin/furan data provided by the unaccredited laboratory were much lower than the data provided by the MOE laboratory, a further requirement was added to the C of A to ensure that the method used for dioxin/furan measurement by the contract laboratory is the same as the method used by MOE, or equivalent to USEPA method A1613. Also in 1998, the Standards Development Branch of the ministry undertook a bioassay to determine the phytotoxicity of the paper fibre material. It was concluded that the material is not phytotoxic and has the potential to be of benefit to certain crops under specific management conditions. A second study to examine metal levels in soils which had been conditioned with PFB over a 7-year period was undertaken and levels of all metals were found to be within the limits for soils after biosolids application, as outlined in the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land (1996)* (Ontario Ministry of the Environment, 2000).

Sound-Sorb

Sound-Sorb is produced by Courtice Auto Wreckers Ltd. by mixing PFB material and screened mineral soil in an approximate 70:30 volume/volume ratio. This material was proposed for use in the construction of sound and bullet attenuation berms at gun clubs around the province. In April 1997, Courtice Auto Wreckers Ltd. obtained a written statement from a professional engineer that the mixture of 77% paper fibre residue and 23% screened mineral soil (weight/weight) provided structural advantages over 100% paper fibre residue for the construction of 16 m high berms. The stability, permeability and sound attenuation was improved with the addition of screened mineral soil. The moisture content was also reduced and porosity was increased which would aid vegetation growth. In May 1997, application was made to Industry Canada to register the name Sound-Sorb as a trademark, and in July 1999 registration was received. On the basis of information available then, MOE technical and legal experts advised that the Sound-Sorb material is exempt from Part V, of the Environmental Protection Act and Regulation 347. Exemption of

the product Sound-Sorb is currently under review by the Ministry of the Environment and Energy.

Sound-Sorb is comprised of paper fibre biosolids from Atlantic Packaging Ltd. and mineral soil which is taken from a location in the vicinity of the site at which the berm is constructed. Consequently, its chemical composition varies to some degree because local mineral soil is used at each location. The sample results presented in this report are representative of the Sound-Sorb berm located at the Oshawa Skeet and Gun Club, lots 4 and 5, Concession 9, City of Oshawa. The berm is estimated to be approximately 90 m long, 20 m wide and approximately 15 m high and has been estimated to contain approximately 27,000 m³ of material.

This report summarizes the findings of the analysis of the fresh paper fibre biosolids produced by the Whitby plant of Atlantic Packaging Ltd. and the Sound-Sorb berm at the Oshawa Skeet and Gun Club. This data will provide the basis for deciding the next steps in the Ministry's review of Sound-Sorb and its future management and the review of the Certificate of Approval issued to Atlantic Packaging Ltd. for the spreading of paper fibre biosolids on agricultural land.

SAMPLING

Sampling of fresh paper fibre biosolids was conducted at Atlantic Packaging Ltd. (Whitby plant) on October 23, 2001. On November 29, 2001 core samples were taken from the berm at the Oshawa Skeet and Gun club and from an undisturbed area on the north side of Coates Rd. across the road from the gun club. The analytical results for these samples are presented in Tables 1 through 5.

Atlantic Packaging Paper Fibre Biosolids

MOE staff sampled the fresh paper fibre biosolids produced at the Whitby Plant. Samples were taken from the storage bunker in which the PFB is stored prior to transport by Courtice Auto Wreckers for either application to agricultural land or the production of Sound-Sorb. It was decided that, based on data collected in 1998 for both the Scarborough and Whitby plant biosolids, the chemistry of the material was similar and did not warrant sampling at both locations. We were advised by the plant supervisor that the pile sampled represented about 2-3 days collection of material. Samples were taken from four different locations within the fresh stockpiles. Sampling was done by digging a hole in the piles to sample material which had minimal exposure to the atmosphere. It should be noted, however, that during the de-watering process, the sludge is centrifuged, put through a belt press and then a screw press. The screw press deposits de-watered material, in small amounts at a time, onto conveyor belts which carry the PFB to the storage bunker. Exposure to the atmosphere during this transport will allow highly volatile organic compounds to escape into the atmosphere. Samples were taken with sterile scoops according to procedures described in the *Laboratory Services Branch Sample Submission Guide, 2001*.

Sound-Sorb Berm Sampling

The berm was hand cored with a 2 cm diameter corer near the base of the berm and examined to determine whether or not there was visual evidence that sewage biosolids had been mixed with the Sound-Sorb, as implied by Gartner Lee Ltd. in their report of July 2001. Visible evidence of this was not found. A corer was also used further up the north slope of the berm. An AMS extendible soil core sampler was used, with 40 cm length polycarbonate tube inserts. The insert allowed removal of an intact section which was immediately capped at either end for transport back to the laboratory. With a new insert, the corer was driven down another 40 cm, beginning at the bottom of the first core. Driving of the corer into the berm material led to compaction of the material. Approximately 120 cm (four feet) of berm material was sampled, but compaction of the material led to a depth measurement of the core material in the laboratory of 80 cm. A second core was taken lower down the berm slope near the green pipe which acts as a drainage pipe from one side of the berm to the other. This core had a total depth of about 90 cm (three feet) at which the base of the berm was reached. This core compacted to a depth of 60 cm upon installation of the corer. The cores were sectioned and submitted to the Ministry's Laboratory Services Branch for analysis.

Background Soil

A background soil core was taken on the north side of Concession 9 (Coates Rd) immediately across the road from the Oshawa Skeet and Gun Club (OSGC). The location was removed from activities on the gun club property. The background soil was cored to a depth of 80 cm. Visual inspection of the core suggested a sandy textured soil with weakly developed horizons. A surface sample (0 - 10 cm section) and a representative subsurface section were submitted to the MOE laboratory for analysis. The background soil core was sampled to provide information about the natural soil in the area of the gun club. It is not the same soil that was used to produce Sound-Sorb. The soil mixed with the paper fibre biosolids to produce Sound-Sorb was taken from a nearby aggregate pit. Although similar in chemistry for many elements, the soil used for Sound-Sorb was higher in limestone than the background soil and, therefore, will have a slightly different inorganic chemistry for elements characteristic of limestone, such as calcium, magnesium and strontium. Further information concerning the chemical data of the mineral soil used in the production of Sound-Sorb is provided in the section Use of Guideline Data and Historic Data.

ANALYTICAL TESTING - GENERAL INFORMATION

Laboratory Testing

All samples were analysed for percent solids and loss-on-ignition, pH, carbon, major nutrients, water extractable chloride, strong acid extractable metals, volatile organic compounds, dioxin/furans, and coliform bacteria. Historical MOE data from 1998 testing of the Whitby plant PFB for chlorophenols, dichlorobenzenes, total PCBs and nonylphenol ethoxylate are also shown

for information purposes. The Sound-Sorb samples, which were taken a month after the fresh PFB material was sampled, were analysed for the same parameters, but the decision was made to also include test requests for extractable sulphate, total and free cyanide, and total sulphur as these were omitted from the fresh PFB test requests. A qualitative extractable organics identification screen performed on the Sound-Sorb and discussions with Laboratory Services Branch staff led to subsequent requests to test for polycyclic aromatic hydrocarbons and total petroleum hydrocarbons. In response to concerns by the public, an experimental method for acrylamide monomer was developed by the Laboratory Services Branch. A brief description of the laboratory methods used can be found in Appendix I.

Laboratory Data

Data referred to in this report are presented in Tables 1 to 5. All data presented in the tables for Atlantic Packaging biosolids, Sound-Sorb and the background soil core are reported on a dry weight basis. If measurements were made and reported on a "field fresh" basis, the results were multiplied by the appropriate factor to correct for the moisture content of the sample to obtain results on a dry weight basis. This allowed for comparison with historical and guideline data. The value qualifier "<" attached to the data indicates that the measurement was less than the detection limit. A value qualifier of "T" indicates a trace amount. The result qualified by "T" represents the actual amount measured in the sample, but because the amount is close to the method detection limit (trace level), the relative standard deviation on the measurement may be higher than if the analyte were present in higher concentrations. In cases where sample results were provided on a field fresh basis with the qualifier T or <, the data was multiplied by the appropriate factor to obtain results on a dry weight basis and the data qualifier was retained. Because the soil samples were air-dried prior to analysis and many of the metals were analyzed on field fresh samples of PFB and Sound-Sorb, the detection limit and "T" qualified data are sometimes higher for PFB and Sound-Sorb samples, once the correction for moisture is carried through the calculation. Data is reported in many different units by the laboratory. A guide to the equivalency of units of reporting used in this report can be found in Appendix II.

USE OF GUIDELINE DATA AND HISTORIC DATA

All data presented in the tables are in the units provided in the left-hand column of each table. For comparative purposes, in cases where guideline levels are included, the guideline data has been converted, where necessary, to the same reporting units as the analytical data. The *Guideline for Use at Contaminated Sites in Ontario (1997)*, Table A, guidelines for recreational/residential land-use purposes in a potable groundwater situation, and Table F, Ontario typical range of uncontaminated background soils are used for comparison. These guideline levels are the concentrations to which, or below which, a site may be remediated if it is determined that contamination of the soil on the site has occurred and the site is to be *redeveloped* for recreational/residential purposes in a potable groundwater situation. The decision to remediate a site to Table A or Table F levels is made in accordance with criteria outlined in the *Guideline for*

Use at Contaminated Sites in Ontario (1997). The Table A concentrations have been developed to provide protection against the potential for adverse effects to human health, ecological health and the natural environment on sites which are not considered environmentally sensitive, in situations where the groundwater is used for drinking (Ontario Ministry of Environment and Energy, 1997). The intended use of these guidelines is for measuring soil contamination on a site by a foreign material deposited on the site. The guidelines are not routinely used for comparison with the chemical concentrations of the foreign material itself. Contaminant concentrations which are higher than guideline levels may occur in material deposited on a site, but the concentration in the soil should remain below the guideline limits if the site is to be sold and redeveloped. If the berm material exceeds guideline levels, a site specific risk assessment should be conducted to determine potential impact to the surrounding environment and the stability of the berm material with respect to chemical leaching.

Ontario Typical Range (OTR) concentrations are listed in Table F of the *Guideline for Use at Contaminated Sites in Ontario (1997)*. These concentrations represent the expected concentrations found in the 0-5 cm depth of recreational area/forest soils in Ontario which have not been subjected to contamination by industrial or commercial activity. These values were determined using the same methods of analysis for soils as shown in Appendix I and represent the 98th percentile concentration of elements and compounds plus two coefficients of variation, determined from representative sampling of soils from all over Ontario. For contaminated site purposes, material with levels less than or equal to those shown in Table F are considered background or inert fill. Inert in this sense is used to imply concentrations within the range of background and which might be expected in uncontaminated soils. It is not meant to suggest that the soil is chemically inert and that normal soil chemical processes will not occur within it. OTR guideline data qualified with asterisks mark parameters which occur naturally in soils in large and variable amounts depending on the soil parent material, and which are not considered to be an environmental risk. These parameters are not listed in Table F but were measured as part of the OTR soil survey. These values represent 98th percentile concentrations and are referred to in the text as OTR98 values. They are included here for information purposes. The asterisked values given for calcium and magnesium are lower than could occur for soils derived from limestone parent materials.

Compost guideline values given are for regular compost (unrestricted use) as defined in Ontario Regulation 101.

For comparative purposes, tables taken from the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land (1996)* are used for examining the Atlantic Packaging paper fibre biosolids. In the case of fresh PFB, the levels are compared to the present and also to the long term target maximum permissible levels of metals in the de-watered biosolids prior to their application on agricultural land. For Sound-Sorb, the biosolid guideline levels are not used as they relate only to the application of PFB to agricultural soil at the application rate of 30 tonnes/ha/yr per 5 year period, as specified in the guidelines.

Analytical results for the Whitby plant biosolids, sampled by MOE in 1998, are shown in Tables 1, 2 and 5. Also shown in Tables 1 and 5 are the mean results obtained from the analysis of Whitby plant biosolids as reported by Maxxam Analytics in the 2000 Atlantic Packaging annual report.

In the text, test results on soils from an aggregate pit close to the Oshawa Skeet and Gun Club are sometimes mentioned. This material was used in the production of Sound-Sorb and MOE tested aggregate samples from this pit in November 2000.

Microbiology test results are discussed in relation to the United States Environmental Protection Agency (USEPA) guidelines for fecal coliform in Class A and Class B biosolids for application to agricultural land. Similar guideline levels to the USEPA are used by the Ministère d'Environnement du Québec. The Environmental Protection Agency guidelines are currently under review and guidelines for Ontario are currently under development.

GENERAL INFORMATION ON SOILS

The unconsolidated glacial overburden deposits of the Oakridges Moraine comprise the parent material in which the soils in the OSGC area have developed over the past 10,000 years. Physical weathering processes including the action of water, ice and temperature act to mechanically break down the mineral material into finer particles. Chemical decomposition processes, such as hydration and hydrolysis, release elements to the soil solution contributing to the synthesis of new minerals. The sand and silt fractions of soils in southern Ontario include common rock-forming minerals such as quartz, feldspar, mica, calcite and dolomite. The finer inorganic fraction of the soil consists of colloidal secondary minerals such as layer silicates (clay minerals), oxides and hydrous oxides. The vegetation supported by the soils contributes organic matter in the form of root material and litter which are incorporated into the upper layer of the soil. In addition to fresh vegetation tissue, humus is present within the soil. Humus is a resistant decomposition end product formed from the action of microorganisms, such as bacteria and fungi, on the organic material. Humus is a dark brown to black colloidal material with a relatively high molecular weight. The effects of the weathering and organic decomposition processes since the last glaciation have transformed the upper 1 to 3 metres of till in Southern Ontario to what we refer to today as soil. Evidence of chemical and microbial processes occurring can be seen in undisturbed soil by the formation of horizons or layers within a soil profile. These layers are distinct from one another in colour, chemistry and microbiology and reflect inorganic and organic decomposition and chemical transport within the soil.

It is generally the finer textured colloidal portion of the soil, consisting of the clay, humus and oxides which control most of the physical and chemical processes occurring in the soil. The retention, release and transport of chemicals through the soil and their availability to plants and the bulk soil solution is largely controlled by this colloid fraction. Colloids are characterized by a plate-like shape and very small particle size (usually $< 2 \mu\text{m}$) resulting in a very high surface area. Broken bonds at the edges of the colloids, ionization of organic functional groups and

isomorphous substitution of elements within the crystal lattice structure of the clay minerals, result in the colloidal material carrying a net charge. In its demand to retain electrical neutrality, the charge is satisfied by the retention of an equal amount of the opposite charge in the liquid phase near the surface of the soil particle. This is done through adsorption/desorption processes and results in the creation of an electric double layer, or an exchange complex of ions, around the colloids. Plants can often take up the ions held in the exchange complex of the soil. In addition to this electrostatic adsorption, a much stronger adsorption, referred to as chemisorption, tightly binds elements in the soil. The humus portion of the soil has been shown, through studies using ^{14}C -labeled organic compounds to irreversibly bind many organic compounds. The results of these processes mean that the colloidal fraction of the soil controls many soil properties including pH, nutrient availability to plants and mobility of inorganic and organic elements and compounds within the soil. The soil can be considered to act, in many ways, like a giant ion exchange column which filters ions from and releases ions to the soil solution depending on chemical conditions within the soil. At the same time, other processes such as precipitation, complexation and chelation occur, elements are continually replenished by microbial decomposition and mineral weathering, microbial action breaks down more complex organic compounds, and some elements are removed from the system through leaching and root uptake. The fate of chemicals and their rate of transport to the groundwater involves many factors including these complex soil processes, depth to groundwater, pore volume, pore distribution and hydraulic conductivity. This is important because the detection of a chemical contains limited information about environmental risk and, as such, its measurement alone does not indicate an acceptable or unacceptable risk. Risks to the environment are determined not only by concentration but by the toxicity and availability of the chemical, and the exposure of a receptor to the chemical of concern. For this reason, the amount present, the amount released and the rate of release of the element or compound is important. The retention and release depends largely on the processes described above.

The addition of clay in the paper making process results in considerable amounts of clay in the final biosolid material. Between 85% - 95% of the kaolin clay added by Atlantic Packaging has a particle size of less than $2\text{ }\mu\text{m}$ (MSDS sheets, Atlantic Packaging, 2001) and, therefore, has the properties of a colloidal material. In addition to kaolin which is an alumino-silicate, talc which is a magnesium silicate mineral is added in the processing. Natural impurities in the talc include quartz (SiO_2) and dolomite ($\text{CaMg}(\text{CO}_3)_2$) (MSDS sheets, Atlantic Packaging, 2001). These minerals are all found in natural soils and their presence will affect the movement of elements and compounds in the PFB material in the same way as they would in natural soils.

RESULTS AND DISCUSSION

pH

pH is a measure of hydrogen ion (H^+) concentration in the soil. Levels above 7 indicate alkalinity or a preponderance of hydroxyl (OH^-) ions and levels below 7 indicate acidity or a preponderance

of hydrogen ions (H^+). In acid soils, aluminum also contributes to acidity as Al^{3+} ions move from the colloidal clays into the soil solution where they are hydrolyzed producing H^+ . In alkaline soils, aluminum does not exist as Al^{3+} but converts to insoluble gibbsite ($Al(OH)_3$) and aluminum hydroxy ions ($Al(OH)_2^+$). In alkaline soils, in addition to the dissolution of calcium carbonate ($CaCO_3$) in the soil, the dissociation of water (H_2O) and the adsorption of H^+ on the exchange complex of clay minerals releases base cations (such as calcium and magnesium ions) which combine with OH^- ions contributing to an increase in pH.

The background soil core sample had a pH of 7.2. The pH of fresh Atlantic Packaging PFB is between 7.5 and 7.7. This pH is a function of the calcium carbonate ($CaCO_3$) in the PFB material and the high base cation concentration in the organic material and clay exchange complex. In the Sound-Sorb, the pH ranges between 8.2 and 8.5. The maximum pH achieved by the dissolution of calcium carbonate in water at saturation levels is 8.5 (unlike calcium oxide (CaO) which reacts with water to form calcium hydroxide (slaked lime), and reaches a higher pH). Agricultural soils are generally limed to a pH of close to 6.5 to provide an optimum condition of available macro- and micronutrients. At a pH of greater than 8 many elements become insoluble.

The higher pH of the Sound-Sorb relative to the fresh PFB material is the result of the addition of mineral aggregate with a higher limestone component. In addition, microbial decomposition of organic matter produces carbon dioxide (CO_2) which reacts with base cations to produce carbonates and bicarbonates. Finally, the release of hydroxyl ions occurs through the exchange of calcium ions from the clay in the Sound-Sorb for H^+ ions in the slightly acidic precipitation.

The pH of the PFB and Sound-Sorb material is within the range of natural soils in the province. Soils developed on the Precambrian rock of the Canadian Shield can have a pH of between 3.0 and 5.5, and the highly buffered soils in Southern Ontario, which have developed on limestone-derived till and bedrock, can have a pH above 7.5. At depth in the glacial till the pH may reach 8.5.

It is also worth noting that the background soil pH was measured in 0.01M $CaCl_2$, the standard method for measuring soil pH. For a number of reasons, measurement of pH in this electrolyte solution better simulates the pH under field conditions and provides a more stable reading. The standard method for soils, however, was not used on the lightweight PFB and Sound-Sorb material: in this material pH was measured in distilled water. In general, the pH of soil solutions, measured using distilled water is approximately 0.5 units higher than pH measured in 0.01M $CaCl_2$. Had the pH of the background core soil been measured in water instead of 0.01M $CaCl_2$, the pH levels would likely have been at or above pH 7.5 and closer to the pH of the fresh Atlantic Packaging PFB material.

% Solids and Loss-on-Ignition:

Atlantic Packaging PFB material has a solids content of between 43% and 47%, and a moisture content of between 53% and 57%. Analysis by Atlantic Packaging has shown that roughly 25%

of the wet weight, or 50% of the dry weight is clay. As previously discussed, kaolin clay is added in the paper-making process.

Loss-on-ignition provides a measure of the combustible material and is used to estimate the amount of organic matter, or paper fibre in the material. In the fresh PFB material, the loss-on-ignition varies between 58% and 62% (dry weight). The % total ash shown in Table 1, represents the clay and the non-combustible mineralized chemical residue of the organic fraction. In the Sound-Sorb material, the % loss-on-ignition varies between 20% and 30%, with the exception of the second Sound-Sorb core at the 24 cm depth. The latter section included soil material from the base of the berm and is, therefore, not representative of Sound-Sorb exclusively. The level of organic matter in Sound-Sorb is similar to levels of organic matter in natural peat soils which are classified as organic soils.

There have been concerns raised by the public about the amount of mineral material added to the PFB in the creation of Sound-Sorb. The producer claims that it is roughly 23% screened mineral soil and 78% paper fibre. Assuming that most of the organic matter in Sound-Sorb is from the PFB material and that little is present in the added screened soil to make Sound-Sorb, we can use the % total ash comparisons between the fresh Atlantic Packaging PFB and berm samples to estimate the amount of external material added in the production of Sound-Sorb. The minimum and maximum amounts of ash in the fresh PFB material are 38% and 42% respectively. The minimum and maximum amounts of ash in Sound-Sorb are 68% and 80% (excluding the berm base sample mentioned above). By subtraction, the percentage *extra* or additional inorganic material added to the PFB to produce Sound-Sorb is estimated at roughly between 26% and 42%. However, because other evidence (discussed later) suggests that significant organic decomposition has occurred in the berm, this estimate is high and a more reasonable estimate is probably 15% - 30% added soil.

A chemical surrogate can also be used as an indicator to provide an estimate of added mineral soil. The surrogate must be an element that is high in the mineral soil, and low in the PFB, or vice versa, and is extremely resistant to chemical and biological weathering. Titanium meets these criteria. Titanium levels in the background soil core were between 550 $\mu\text{g/g}$ and 600 $\mu\text{g/g}$. The mean level of Ti in the fresh PFB material was 17 $\mu\text{g/g}$. Mixing of mineral soil at about 20% to 30% in Sound-Sorb should yield Ti concentrations of between 125 $\mu\text{g/g}$ and 210 $\mu\text{g/g}$. Concentrations measured in the Sound-Sorb were within this range.

Metals

Metals exist in soils in widely varying amounts depending on the metal. Some are major contributors to the structure of rock-forming minerals while others are present in very small to undetectable amounts. Many trace metals are essential for plant nutrition but can be harmful to plants if present in large amounts. The solubility of trace metals is dependent to a large degree on the pH and oxidation state of the soil, but for most metals solubility is highest in acid soils (pH less than 5) and at lower redox potentials (anaerobic, reducing conditions). Exceptions to this

include molybdenum and boron. Transport of metals in soil is also strongly controlled by the colloidal inorganic and organic portions of the soil. Complexation, chelation and adsorption processes make modeling trace metal transport in the unsaturated zone of the soil extremely complicated. For this reason most studies done on metal movement through the soil involve experimental lysimeter studies.

Arsenic (As)

The range of arsenic levels in uncontaminated soils is from less than 1 µg/g to over 50 µg/g, with the lowest levels occurring in sandy soils (Kabata-Pendias and Pendias, 1985). Arsenic in surface soils may be enriched by atmospheric deposition in areas of metal processing or in areas where pesticides were previously sprayed, such as in orchards. Arsenic is naturally associated with metal-bearing rocks and ores. In soils, As mobility is governed by its oxidation state and limited by its strong adsorption to clays, Fe and Al hydrous oxides and organic material, as well as its precipitation with calcium carbonate (CaCO₃).

Arsenic in fresh PFB material varies from 0.55 µg/g to 0.74 µg/g and in Sound-Sorb from 0.92 µg/g to 1.6 µg/g. Levels in the fresh PFB are below both the present guideline level (170 µg/g) and long term target level (35 µg/g) for As in biosolids that are applied to agricultural land. The concentrations in Sound-Sorb are significantly lower than the Table A, contaminated site guideline for surface soils, in a recreational/parkland land use under potable water conditions (20 µg/g). They are also below the Table F, typical background range level for uncontaminated soils in Ontario (OTR) (17µg/g). Both fresh biosolids and Sound-Sorb have As concentrations lower than the background soil core at the site which has a concentration of 2.2 µg/g at the surface and 1.8 µg/g at depth. It is unclear why the levels reported by Gartner Lee Ltd. were higher (Gartner Lee Ltd., 2001) but MOE's values were confirmed by the 1998 testing undertaken at the MOE laboratory and by the private laboratory, Maxxam Analytics, used by Atlantic Packaging in 2000 to analyze the PFB material.

Selenium (Se)

Selenium tends to be low in Ontario soils with a Table F, Ontario Typical Range (OTR) of 1.9 µg/g. It was not detected (< MDL) in the sandy background soil. Selenium levels in Atlantic Packaging PFB are less than 0.1 µg/g and are close to 0.1 µg/g in the Sound-Sorb. The slightly higher Se levels in the Sound-Sorb may be due to the presence of a higher Se concentration in the added screened mineral soil than in the PFB material. As the detection limit for Se in soil is 0.2 µg/g this could not be conclusively determined. Se levels are lower than all guidelines used for comparison.

Mercury (Hg)

Mercury in the fresh PFB and Sound-Sorb occurs in trace amounts (0.05 µg/g) and at trace concentrations in the background soil (0.02 µg/g - 0.03 µg/g). Mercury is expected to be low in the sandy glacial overburden of the moraine. All Hg values in the Sound-Sorb were lower than the Table F, OTR of 0.23 µg/g, and considerably lower than the Table A contaminated site guideline for Hg (10 µg/g) and the federal soil quality guideline for soil (6.6 µg/g) (CCME, 1997). Mercury in the fresh PFB is lower than the present (11 µg/g) and long term (1.4 µg/g) biosolid

guideline concentration for application to farmland. Evidence is mounting that much of the mercury present in the environment, in areas remote from industrial sources, is the result of the long range transport of air pollutants (Schroeder and Munthe 1998; Fitzgerald, et al. 1998). Mercury in a water sample from a seep within the berm, taken in October 2001, was present at a concentration of 0.016 µg/L. The Ontario drinking water standard for Hg is 1 µg/L (Ontario Ministry of the Environment, 2001) and the provincial water quality objective (PWQO) for surface water is 0.2 µg/L (Ontario Ministry of the Environment, 1994).

Aluminum (Al)

Aluminum, along with silica, is one of the main building blocks of rock minerals and its concentrations are usually discussed in terms of percentages (10,000 µg/g = 1%). The resistance of minerals to hydrolysis, an important chemical weathering process, depends on the strength of the bonds in the mineral structure. Si-O and Al-O bonds present in most minerals are very strong, and although large amounts of Al and Si exist in soils, low concentrations are found in soil solutions. Moreover, when minerals such as feldspar do weather, Si and Al are released but quickly form secondary minerals. Aluminum hydroxides are formed during mineral weathering ($\text{Al}(\text{OH})_3$, $\text{Al}(\text{OH})_4^-$) and form the backbone of secondary clay minerals. Kaolinite is a secondary clay mineral and is a weathering product of potassium feldspar (orthoclase) (KAlSi_3O_8). Aluminum solubility increases sharply at pH levels of less than 5.5 and contributes to acidity, as mentioned in the section on pH. At an alkaline pH, kaolinite very slowly begins to solubilize as $\text{Al}(\text{OH})_4^-$ (Bolt and Bruggenwert, 1976). Because aluminum is abundant in the earth's crust, contaminated site guidelines for aluminum have not been developed.

Aluminum in Atlantic Packaging biosolids are between 3540 µg/g (0.35%) and 4860 µg/g (0.49%). The presence of the aluminum in this material is likely contributed primarily from the kaolinite clay (general formula = $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) in the PFB material. The berm exhibits levels similar to fresh PFB material. Aluminum concentrations in the soil background core at the site are higher (6600 - 6800 µg/g, 0.66% - 0.68%). All concentrations are lower than Al levels reported for uncontaminated sandy loam agricultural soils in Scugog Township, where concentrations of 9,000 µg/g (0.9%) were reported (Ontario Ministry of the Environment, 2000). The concentration of Al found in soils which are naturally very high in clay may be much higher, as seen in the OTR98 value of 30,000 µg/g (3%). In the berm, which has a pH above 8, aluminum hydroxides are not soluble and significant dissolution is not a concern even as the kaolinite begins to weather. Aluminum is prone to complexation in the presence of humic and fulvic acids and can become mobile, although it generally precipitates at depth.

Aluminum concentrations in aquatic systems are usually less than 1 mg/L. Toxicity to aquatic life is strongly related to the species of Al. Inorganic monomeric aluminum present in acid lakes in northern Ontario has been shown to impede the reproduction of a variety of fish species (Hutchinson et al., 1989; Hutchinson and Holtz, 1989). Provincial water quality objectives for total aluminum have been set at 0.075 mg/L for lakes and rivers having a pH of greater than 6.5. This low level ensures the protection of the most sensitive fish species. Aluminum was not detected in water which had collected in seeps within the berm in October 2001.

Concern was raised by residents in Durham about a surface water sample taken from a small pond of water at Courtice Auto Wreckers Ltd.'s aggregate pit where PFB was previously stored. The sample contained Al at a concentration of 0.28 mg/L, which is above the PWQO level set for lakes and rivers. In ponds of turbid surface water which also contain large amounts of dissolved organic carbon (DOC) as occurred at this particular location, the measurement of aluminum is complicated by the association of Al with the clay fraction of the suspended sediment ($< 2 \mu\text{m}$ particle size) and the presence of aluminum associated with organic colloids in the water. Unless field filtration is undertaken prior to analysis, falsely high results may be obtained when methods such as atomic absorption spectrophotometry and inductively coupled plasma emission spectrometry are used. Finely divided clay and organic colloids encounter very high temperatures (e.g. 5000°C plasma) and are broken down releasing aluminum during analysis. The known measurement error due to the presence of colloidal clays and the need for filtration is addressed in the PWQO document (Provincial Water Quality Objectives, 1994). Although not directly related to this study, the above situation emphasizes the need for membrane filtration when monitoring surface water for aluminum. Furthermore there is a difficulty in applying PWQO criteria which are designed for lakes and rivers to small bodies of standing surface water on a property, because the guidelines represent end concentrations and, as such, serve as a starting point from which criteria for effluent/stormwater concentrations can be designed, based on the assimilative capacity of the receiving water body.

In order to ensure effective water treatment operations, the Ontario drinking water operational guideline for residual aluminum is set at 0.1 mg/L and is not a health-related guideline. This level ensures the efficiency of the alum (hydrated aluminum sulphate) used in the treatment process and prevents coatings on pipes in the treatment system. The potential health effects of Al have not been clearly shown (Ministry of the Environment, 2001).

Barium (Ba)

Barium is commonly present in rock-forming minerals and the Table F, background OTR concentration for Ba is $210 \mu\text{g/g}$. Atlantic Packaging PFB material, Sound-Sorb and the background soil core are all significantly below this level with concentrations ranging from only $27 - 43 \mu\text{g/g}$. Barium is primarily found in inorganic forms, is stable in the 2^{+} valence state, is strongly adsorbed by clays and forms hydroxides. It is quickly and easily precipitated as a carbonate or sulphate rendering it immobile, especially in alkaline soils ($\text{pH} > 7.0$). The high percentage of clay in the PFB material, the pH above 7 and the relatively high sulphate concentration in the PFB and in Sound-Sorb will restrict leaching of barium. Barium that is leached from the PFB material may be released as the chloride, given the abundance of chloride in this material and the solubility of barium chloride relative to other barium compounds.

Although common in soils, barium levels are low in uncontaminated aquatic ecosystems (usually less than 1 mg/L). In aquatic systems, barium concentrations are largely controlled by the availability of sulphate which is generally present in high enough concentrations in surface waters to effectively precipitate barium. There is not a provincial surface water objective for barium. The drinking water standard for Ba is 1 mg/L (Ontario Ministry of the Environment, 2001).

The barium concentrations in the PFB samples make it acceptable for application to agricultural land at the application rate outlined in the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land (1996)*. Barium is likely held as the sulphate, carbonate and by clays in the PFB material. In high application situations such as the Sound-Sorb berm, the possibility for anaerobic conditions within the berm and the high levels of chloride in the material could contribute to barium leaching. However, only 0.23 mg/L Ba was found in October 2001 in a water sample taken by MOE from a seep within the berm, and Gartner Lee Ltd. reported 0.4 mg/L Ba in an acid leachate of the berm material.

Beryllium (Be)

Beryllium is present in rock forming minerals and tends to be associated with minerals with high silica concentrations. Upon weathering, clays inherit nearly all of the beryllium released, which only amounts to a few $\mu\text{g/g}$ (National Research Council, 1977). Beryllium is present in oxide forms and in alkaline environments it combines with carbonates (Kabata-Pendias and Pendias, 1984). Beryllium salts such as beryllium chloride (BeCl_2) and beryllium sulphate (BeSO_4) are relatively soluble and can be leached from soil. The levels of beryllium found in Atlantic Packaging PFB, Sound-Sorb and the background control soil core were all less than the detection limit and lower than the typical range of beryllium in uncontaminated Ontario soil (1.2 $\mu\text{g/g}$).

Cadmium (Cd)

Cadmium occurs in small amounts in the parent material of most soils in Ontario and is usually present in amounts less than 1 $\mu\text{g/g}$. Soils in remote areas, free from anthropogenic Cd, usually have concentrations less than 0.5 $\mu\text{g/g}$. Cadmium mobility in soils is largely controlled by pH and redox potential. Under oxidizing conditions and at a pH above 8, Cd forms oxides and carbonates. The solubility of Cd^{2+} and its availability to plants is greatest in acidic soils (pH < 5). Cadmium solubility decreases with increasing pH and reaches its lowest level at a pH above 8. Cadmium is also strongly adsorbed by the colloidal clay fraction of the soil. Based on this behaviour, increasing the pH and cation exchange capacity of the soil has been used to amend soils high in Cd.

When available to plants in large amounts, Cd can accumulate in the environment. For this reason the Ontario Drinking Water Objective for Cd has been set at 0.005 mg/L. Cadmium is also present in cigarette smoke, in atmospheric pollution in industrialized areas and can be released to drinking water through the corrosion of plumbing systems. Cadmium levels in the fresh PFB material, the Sound-Sorb berm and the background soil core are all less than 1 $\mu\text{g/g}$ with one sample equal to 1 $\mu\text{g/g}$. Cadmium present in the berm would be quickly immobilized because there is a large amount of clay in the PFB material and the pH is above 8. Cadmium is lower than all the guidelines used for comparison with one sample equal to the Table F. typical range of background Ontario soils.

Calcium (Ca)

Calcium is a major component of minerals in the earth's crust, and is particularly plentiful in soils derived from calcite and dolomite-bearing rocks such as the Paleozoic limestone in Southern Ontario. Much of the glacial overburden in Southern Ontario is derived from this limestone.

Feldspars which are present in the older Precambrian rocks of northern Ontario are sources of lesser amounts of Ca. As a result, Ca concentrations in soils vary considerably from a few thousand $\mu\text{g/g}$ to greater than 50,000 $\mu\text{g/g}$. In soils high in calcium, much of the Ca is held in the easily exchangeable form and is available to plants. Soils containing calcite and dolomite generally have an alkaline pH and soils developed on parent materials with calcium-poor minerals generally have an acid pH.

Carbonate associated with Ca and Mg is present in the PFB material in amounts ranging from 1.5% to 2%, resulting in a pH above 7. Dissolution, through carbonate equilibria reactions with rainwater, releases Ca to the exchange complex of the clay in the PFB material and to the soil solution. Calcium is also contributed in large amounts by organic matter and is generally high in compost.

The sandy background soil core samples near the OSGC site were low in Ca, with a concentration of only 3500 $\mu\text{g/g}$ in the sub-surface mineral soil, much of which is probably derived from feldspars in the sand. Concentrations of 9,500 $\mu\text{g/g}$ are found in the organic surface background soil. Calcium in fresh PFB ranged from 51,000 $\mu\text{g/g}$ to 68,000 $\mu\text{g/g}$. The Sound-Sorb core samples have Ca concentrations close to the levels found in the PFB material with the exception of the 0-10 cm depth of one core which has a concentration of 100,000 $\mu\text{g/g}$. Previous testing of material in the aggregate pit from which material was taken for the production of Sound-Sorb, showed Ca levels of 100,000 $\mu\text{g/g}$. This is in keeping with the carbonate-rich glacial deposits of southern Ontario. It is expected that the soil water in the berm material will be high in calcium. The calcium-rich material will have a similar effect as lime when applied to agricultural soils.

Cobalt (Co)

Cobalt concentrations range from less than 1 $\mu\text{g/g}$ to over 100 $\mu\text{g/g}$ depending on the type of rock. In granite, shales and sandstones, Co may be present in concentrations of up to 20 $\mu\text{g/g}$. Cobalt is most soluble in oxidizing, acid environments and its adsorption by manganese oxides increases with increasing pH (Kabata-Pendias and Pendias, 1984). Cobalt is present at trace levels in the PFB and Sound-Sorb, close to concentrations in the background soil core (2.7 to 3.4 $\mu\text{g/g}$) and all are much lower than the Table F, background OTR concentration of 21 $\mu\text{g/g}$.

Chromium (Cr)

Chromium concentrations in soils can vary considerably from a few $\mu\text{g/g}$ to hundreds of $\mu\text{g/g}$ depending on the rock-forming minerals in the soil. Chromium is amphoteric, meaning that it can exist in waters in more than one valence state. Cr^{3+} is the form of Cr released during mineral weathering, and its solubility increases with decreasing pH. This form is not considered toxic (Ontario Ministry of the Environment, 2001). Hexavalent chromium (Cr^{6+}), however, is harmful to the environment.

The PWQO for total Cr is 0.1 mg/L and the ODWO is 0.05 mg/L primarily because of its potential to oxidize to Cr^{6+} during chlorination. Chromium solubility and valence state is largely controlled by pH and oxidation conditions within the soil.

Chromium levels in fresh PFB material (2.6 µg/g to 6.7 µg/g) are lower than the background soil core (9 µg/g - 10 µg/g) and lower than all guidelines used for comparison. Sound-Sorb berm cores showed levels within the range of the background soil and all are less than the Table F, OTR value of 71 µg/g.

Copper (Cu)

Copper occurs naturally in minerals and is higher in igneous rocks where it is present in levels ranging from 40 to 100 µg/g (Kabata-Pendias and Pendias, 1984). The Table F, OTR for uncontaminated soils is 85 µg/g. Copper is required for plant growth and although the requirement is different depending on the species, its availability in the soil determines whether deficiency or toxicity will occur. Copper is adsorbed strongly and readily by the clay and organic colloidal material in the soil. The degree of Cu adsorption is controlled by surface charge which is a function of pH. The solubility of the various Cu species is lowest at pH levels of between about 7.5 and 10. Carbonates also have the ability to bind Cu. Copper is considered to be one of the least mobile elements in soil and movement is insignificant (Bolt and Bruggenwert, 1976), yet relatively high copper concentrations are found in all soil solutions. This is attributed, in large part, to the formation of soluble organic chelates of Cu.

The Cu concentration considered to be toxic to aquatic life depends strongly on the alkalinity of the water. The levels of Cu shown to be toxic to aquatic species in the soft water lakes of the Canadian Shield are much lower than in the hard water lakes of Southern Ontario. Consequently, the PWQO for Cu is different depending on the alkalinity of the water. For lakes with hardness levels greater than 20 mg/L as CaCO₃ the PWQO is 5 µg/L whereas for soft water lakes the PWQO is 1 µg/L. The aesthetic Ontario drinking water objective for copper is 1 mg/L and is not health-related but is related to the water's taste and potential for laundry staining (Ontario Ministry of the Environment, 2001).

Copper concentrations in the Atlantic Packaging PFB material range from 120 to 139 µg/g. This is higher than the Table F OTR concentration of 85 µg/g and higher than the compost guideline (60 µg/g) for unrestricted use. The PFB Cu concentration, however, is lower than both the present and long-term target levels for Cu in biosolids for application to agricultural land (1700 and 380 µg/g respectively) (Ontario Ministry of the Environment, 1996). Furthermore, acceptable Cu concentrations were found in the soil during a study of Durham Region soils on which PFB material had been applied over a period of 7 years. (Ontario Ministry of the Environment, 2000).

Copper concentrations in the Sound-Sorb berm were lower than fresh PFB and ranged from 58 to 80 µg/g, as a result of the incorporation of mineral material to produce the Sound-Sorb. Consequently, Cu in the berm is present at a concentration below the Table F, OTR guideline (85 µg/g). Trace amounts of Cu (3 µg/g and 5 µg/g) were found in the background soil core, and levels in the aggregate material of the nearby gravel pit where Sound-Sorb was produced are similar (5 µg/g and 7 µg/g). The Cu in the berm will likely adsorb to the clay within the berm and the pH above 8 will favour the precipitation of hydroxides. Evidence of restricted Cu movement within the berm is seen in the trace amount of Cu found in core 3 at the base beneath the berm.

Moreover, Cu was not detected in a water sample taken by MOE in October, 2001 from a seep within the berm, and Gartner Lee Ltd. reported that acid-leachable Cu in the berm was less than the detection limit in one sample and 0.007 mg/L in the second sample (Gartner Lee Ltd. 2001).

Iron (Fe)

Iron is a major element in rock-forming minerals. The OTR98 is 35,000 µg/g. Acid, reducing conditions in the soil generally favour its movement and alkaline, oxidizing conditions generally favour its precipitation. The movement of Fe within the soil, however, is also largely influenced by its ability to be chelated by organic acids and the ease with which it can change valence states. The levels found in Atlantic Packaging PFB material are considered low (374 µg/g - 474 µg/g). Concentrations found in the background soil core (11,000 µg/g - 13,000 µg/g) far exceed the concentrations found in the PFB material, and evidence of the addition of mineral soil to Sound-Sorb is seen in the iron concentration of the berm cores which are between 2900 µg/g and 8700 µg/g. The latter occurs in the sample taken at the base of the berm core which contained a much higher percentage of mineral soil.

The aesthetic drinking water objective for Fe is 0.3 mg/L and is related to taste and staining of plumbing fixtures (Ontario Ministry of the Environment, 2001) and the PWQO for Fe in surface water is also 0.3 mg/L. Iron concentrations in the PFB material are below the background soil levels. The mineral soil within the berm, however, may contribute Fe to soil water if anoxic conditions occur in the berm. An unfiltered sample of water from a seep within the berm showed 7 mg/L Fe in October, 2001.

Lead (Pb)

Lead is considered a trace element in the earth's crust and although the concentration of Pb in magmatic rocks can be high (~40 µg/g), most uncontaminated mineral soils in southern Ontario are expected to contain less than 10 µg/g Pb. Surface soils in industrialized parts of the world, however, often contain levels considerably higher than 10 µg/g as a result of the atmospheric deposition of Pb from industrial activities and the previous use of Pb alkyls in gasoline. The widespread addition of Pb to soils from the burning of gasoline has led to many studies concerning the movement of Pb through the soil. It is generally accepted that the input of Pb to soils far exceeds its output and it is held relatively immobile through adsorption by clay minerals and Fe oxides and its precipitation with carbonate and phosphate (Kabata-Pendias and Pendias 1984).

Lead in fresh PFB material occurred at trace amounts less than 10 µg/g. It is present at a concentration of 22 µg/g in the surface sample of the background soil core and at less than 10 µg/g in the subsoil. In the Sound-Sorb material, concentrations varied between approximately 9 and 30 µg/g. These levels are far below the Table F, OTR level of 120 µg/g for surface soils in parkland/forested areas, lower than the Table A soil concentration guidelines for a recreational land use situation with potable groundwater (200 µg/g) and lower than the federal soil quality guideline of 140 µg/g (CCME, 1997). The Ontario drinking water standard for Pb is 10 µg/L (Ontario Ministry of the Environment, 2001) and the PWQO is 3 µg/L (Ontario Ministry of the Environment, 1994).

Magnesium (Mg)

Magnesium is a macro element in rock-forming minerals, existing in feldspar, dolomite, talc, within the lattice of many clay minerals and in a variety of other common minerals in Ontario soils. Magnesium, although present in large amounts, is generally found in lower concentrations than calcium in soils. Mg^{2+} can substitute for Al^{3+} within the lattice of clay minerals, contributing to the isomorphous charge of the clay colloid. Plant available Mg is also held in large amounts in the exchange complex of the colloids. Magnesium is not of concern as a toxic element in drinking and surface water, and contaminated site guidelines have not been set for Mg. As a major plant nutrient, Mg is recycled to the soil by decaying organic matter.

The Mg concentrations in the fresh PFB material are in the order of 850 µg/g - 1020 µg/g. This is likely influenced by the presence of talc in the biosolids and dolomite impurities in the kaolin clay added. Levels are far below the OTR98 of 20,000 µg/g. The background soil core shows concentrations of 1600 µg/g and 2000 µg/g Mg, and levels within the Sound-Sorb berm vary between 2900 µg/g and 3200 µg/g. The latter are similar to levels found in the aggregate pit material.

Manganese (Mn)

Manganese is abundant in rocks, reaching levels of several thousand µg/g depending on the types of minerals present. In soils, Mn exists in many oxidation states (Mn^{2+} , Mn^{3+} , Mn^{4+}) although Mn^{2+} is the most common. Secondary minerals formed after the release of Mn from primary mineral weathering are common in soils and a large variety of stable and meta-stable Mn oxides and hydroxides are formed. Mn oxides and hydrous oxides are complex and play a significant role in the adsorption of other elements in the soil.

Manganese levels in Atlantic Packaging PFB are low (27 µg/g - 35 µg/g), far below the OTR98 of 2200 µg/g. Given the variable concentrations and abundance of Mn in soils, contaminated site guidelines for Mn have not been developed. Manganese concentrations in the background soil core are higher than the Sound-Sorb berm, and the berm material exhibits Mn concentrations between background soil and fresh PFB Mn concentrations, reflecting the addition of mineral soil to produce Sound-Sorb.

Molybdenum (Mo)

Molybdenum is a rare element in the earth's crust, yet in small amounts it is an essential element for plants. The main mineral containing Mo is a sulphide and is unlikely to be present in the soils or glacial overburden in southern Ontario. In granitic rocks and sandy soils derived from them, Mo can be present in levels close to 2 µg/g, whereas clays and organic soils often contain higher amounts in the range of 3 µg/g to 5 µg/g. Molybdenum mobility is largely a function of its valence state, however, it is rare among the trace elements in that its mobility increases in alkaline conditions rather than in acid conditions. In acid soils and in soils with large amounts of Fe, Al and Mn oxides, Mo is sparingly available to plants. Molybdenum is absorbed by plants as MoO_4^{2-} and is taken up more efficiently in the presence of phosphorus (Ontario Ministry of Agriculture, Food and Rural Affairs, 1998).

Molybdenum concentrations in the PFB material are between 0.4 µg/g and 3.4 µg/g, less than the present allowable concentration in biosolids (94 µg/g). The background soil core contains Mo levels less than 0.5 µg/g. In the Sound-Sorb samples, Mo occurs in amounts varying from less than the detection limit to trace amounts of 1.6 µg/g. This is below the Table F, OTR of 2.5 µg/g. The small amounts of Mo present are probably soluble in the alkaline pH conditions of the berm, with the possibility of soluble thiomolybdate formation under anaerobic conditions in the presence of sulphur. The provincial water quality objective (PWQO) for surface water is 0.01 mg/L for the protection of aquatic life. There is no health-related Ontario drinking water standard (Ontario Regulation 459/00), however, Table A of the contaminated site guidelines recommend a remediation level of 7.3 mg/L for potable groundwater (Ontario Ministry of Environment and Energy, 1997). It is likely that, if the trace amounts of Mo in the berm moved into the soil below, the Mo would be quickly immobilized at the near neutral pH of the underlying mineral soil and by the Fe and Al hydrous oxides present in the underlying soil.

Nickel (Ni)

High nickel concentrations in rocks and soils tend to be associated with ferro-magnesian minerals. Soils developed from granitic material and most sedimentary material tend to be lower in nickel. For the most part, Ni is higher in clay-rich, organic soils than in sandy mineral soils. Ranges of 0 - 50 µg/g are common in soils in Ontario, depending on the parent material in which the soil developed. Colloidal fractions of the soil, including Fe and Mn sesquioxides, largely control Ni availability in soil. Nickel is an essential micronutrient and is taken up as Ni^{2+} , particularly by legumes (Ontario Ministry of Agriculture, Food and Rural Affairs, 1998).

Nickel is present in amounts ranging from less than the detection limit of 1.2 µg/g to trace amounts of 3.5 µg/g in fresh Atlantic Packaging PFB material. The Sound-Sorb material contains low and similar amounts to the background soil core. The uncontaminated background soil samples are representative of sandy loam soils which, if derived from granites or sedimentary carbonates, generally have Ni concentrations of less than 10 µg/g (National Research Council, 1977). Material from the nearby aggregate pit contains levels of 4 µg/g to 5 µg/g Ni. The background Table F, OTR for Ni is 43 µg/g and the Table A guideline for remediation for residential/recreational land in a potable groundwater situation is 150 µg/g.

Potassium (K)

Potassium is a major element in rocks and soils in Ontario and is particularly high in micas and in mica-derived clay minerals, as well as in K-feldspar (orthoclase). While the K in these minerals is plentiful, these minerals weather slowly. Once K becomes available it can be quickly fixed within the lattice of illite and vermiculite clay minerals. Potassium is readily soluble and held in the exchange complex of the soil. It is quickly taken up by plants and is easily leached from soil. As a result sandy, well-drained soils are often low in K. When these soils are used for agricultural purposes, K supplements are often necessary in the form of potash fertilizers.

Potassium does not pose an environmental risk and PWQOs, drinking water standards and contaminated site guidelines have not been set for K. The background OTR98 level for K of 6500 µg/g is for information purposes only. Potassium levels in the background core samples are

low (490 µg/g - 510 µg/g) but are higher than the levels in the fresh PFB material (230 µg/g - 250 µg/g). The 1500 µg/g - 2100 µg/g concentrations in the berm are higher than a mixture of PFB with background soil but are still below OTR98 levels. The higher levels in the berm may be the result of mica minerals in the aggregate mineral soil used to produce Sound-Sorb. It is also possible that K from the compost on the surface contributes to the K concentration, however, there was an insufficient surface sample from the core to determine this. Potassium is advantageous to the vegetation growing on the berm.

Silver (Ag)

Silver occurs in very small amounts in soils, usually in concentrations from less than 1 µg/g to 3 µg/g. At a soil pH above 4, Ag is not mobile. Complexation of Ag makes soils rich in organic matter higher in Ag, where levels can reach as high as 5 µg/g (Kabata-Pendias and Pendias 1984). Silver in Atlantic Packaging material varies from a high of 1.2 µg/g to less than the detection limit of 0.2 µg/g. In the Sound-Sorb material concentrations are less than 0.2 µg/g, lower than the Table F, OTR of 0.42 µg/g and considerably lower than the Table A, clean-up guideline level of 20 µg/g for residential/recreational parkland in a potable groundwater situation.

Sodium (Na)

Although not an essential plant nutrient, sodium exists in moderate amounts in soils derived from Na-feldspar (plagioclase). Sodium released by weathering is held in the exchange complex of soils and is easily leached from the soil under normal pH conditions. Sodium is generally only a problem in arid soils where leaching is minimal and the capillary action within the soil causes Na to accumulate at the surface where it can become toxic to plants. In the humid temperate climate of Ontario Na accumulation is not a problem. The OTR98 concentration for Na (910 µg/g) is shown for information purposes only and a contaminated site guideline for Na has not been developed. The Ontario, drinking water standard for Na is 20 mg/L for people on Na-restricted diets. There is no PWQO for Na.

The background soil core is low in Na (110 µg/g - 140 µg/g). Sodium in the fresh PFB material ranges from 900 µg/g - 1100 µg/g, close to the OTR98 value of 910 µg/g. The mean concentration of Na in the fresh PFB samples tested was 960 µg/g, which is higher than the OTR98 level of 910 µg/g. At a PFB application rate of 30 tonnes wet weight/ha, the amount of Na added to agricultural soils remains below the recommended annual maximum Na addition for sandy soil (200 kg/ha) as outlined in the *Guideline for the Utilization of Biosolids and Other Wastes on Agricultural Land, 1996*.

The berm material contains 530 µg/g - 540 µg/g Na, lower than the OTR98 level. If Na is present in a large amount in the exchange complex of soils, it may hydrolyze causing an increase in soil pH. The large amounts of neutral salts in the berm material, however, would prevent a significant rise in pH above 8.5.

Strontium (Sr)

Strontium is a common element found in sedimentary rocks containing calcite and dolomite (limestone) and in the glacial tills derived from them, as well as in plagioclase feldspar, a common

mineral in granite. Strontium is strongly coupled with Mg and Ca in soils and rocks and behaves geochemically in much the same way. Consequently, Sr concentrations in soil can be in the thousands of $\mu\text{g/g}$. The OTR98 for soils in Ontario is $78 \mu\text{g/g}$ but this may be higher in soils developed from limestone. Contaminated site guidelines, PWQOs and drinking water standards have not been developed for total Sr. ^{90}Sr is a result of radioactive fallout and is hazardous and persistent. The drinking water standard for ^{90}Sr is 5 bq/L .

Total strontium concentrations in the fresh PFB material are between $49 \mu\text{g/g}$ and $53 \mu\text{g/g}$ and may be associated with calcium and magnesium carbonates in the biosolids. Levels in the background soils are between $11 \mu\text{g/g}$ and $20 \mu\text{g/g}$. The Sr concentration in the Sound-Sorb berm is between $61 \mu\text{g/g}$ and $118 \mu\text{g/g}$ and the amount varies similarly with Ca. The high levels of Sr in the Sound-Sorb are attributed to higher levels of Sr in the limestone-rich aggregate pit soil.

Titanium (Ti)

Titanium is present in large amounts in rock-forming minerals but is very resistant to weathering. Concentrations of hundreds and even thousands of $\mu\text{g/g}$ in uncontaminated soils are not considered unusual. Titanium is not considered an environmental concern and consequently Ontario's drinking water standards and PWQOs do not include Ti. Titanium concentrations in the fresh PFB materials are low ($16 \mu\text{g/g}$ - $19 \mu\text{g/g}$). The higher levels in the Sound-Sorb samples ($124 \mu\text{g/g}$ - $193 \mu\text{g/g}$) reflect the mixing of mineral soil into the Sound-Sorb. The background soil core has Ti concentrations of between $550 \mu\text{g/g}$ and $600 \mu\text{g/g}$. All concentrations are below the OTR98 level of $5200 \mu\text{g/g}$.

Vanadium (V)

Vanadium is present in many minerals and is present in mafic and felsic igneous rock and also in sedimentary deposits, sometimes in amounts reaching hundreds of $\mu\text{g/g}$. Upon weathering, V tends to be held by Fe oxides and clays and its mobility is controlled in part by its oxidation state and pH. Vanadium is also contributed to the environment by the burning of fuel oils. Vanadium in the fresh PFB material is low ($3.3 \mu\text{g/g}$ - $4.4 \mu\text{g/g}$) with slightly higher amounts present in the Sound-Sorb berm cores ($6 \mu\text{g/g}$ - $16 \mu\text{g/g}$). The high concentration ($16 \mu\text{g/g}$) occurred at the base of the second core where underlying material was mixed in with the Sound-Sorb. The background soil core contained higher V concentrations ($21 \mu\text{g/g}$ and $25 \mu\text{g/g}$) than the Sound-Sorb cores. All samples are below the Table F, OTR level for V of $91 \mu\text{g/g}$.

Zinc (Zn)

Zinc is an essential trace element and is present in moderate amounts in parent rocks and soils. Zinc occurs in all types of minerals, but is generally lowest in carboniferous rocks. Zinc is readily weathered but tends to form insoluble compounds at alkaline pH levels. Zinc is also adsorbed by clays, Fe and Al hydrous oxides and humus. It is easily taken up by plants as Zn^{2+} and recycled to the surface soil by decaying vegetation, often resulting in the accumulation of Zn in surface horizons. Zinc concentrations in uncontaminated soils can be higher than $200 \mu\text{g/g}$, although levels between $20 \mu\text{g/g}$ and $50 \mu\text{g/g}$ are more common.

In the fresh PFB material, Zn concentrations are between $51 \mu\text{g/g}$ and $81 \mu\text{g/g}$. The background

soil samples contain 28 µg/g - 44 µg/g Zn, and the Sound-Sorb samples contain between 19 µg/g and 102 µg/g Zn. The low amount is found at the base of core 2 which contained underlying soil, and the high amount is found in the 0-10 cm layer containing the compost which was placed on the surface of the berm. The Table A soil remediation guideline for zinc is 600 µg/g, and the Table F OTR level is 160 µg/g. Zinc levels in the berm are below these guidelines. The taste-related aesthetic Ontario drinking water objective for Zn is 5 mg/L (Ontario Ministry of the Environment, 2001). The PWQO for Zn is set at 20 µg/L for the protection of aquatic life in lakes and rivers. Zinc was not detected in October 2001 in the water from a seep within the berm.

Carbon (C)

Carbon is a primary constituent in organic matter and when in the soil in this form, it is referred to as organic C. Inorganic C is present in primary and secondary carbonate minerals. Carbon cycles through the soil in many different forms. Carbon dioxide (CO₂) is produced as the C in organic matter is oxidized by the microorganisms within the soil. This CO₂ is free to react to form carbonic acid (H₂CO₃) and, if conditions are favourable, to form calcium, magnesium and sodium bicarbonates and carbonates.

In the fresh Atlantic Packaging biosolids, organic C is contributed by the paper fibres and inorganic C (carbonate-C) is contributed by the mineral portion of the PFB material. Organic C levels are high (25% to 26%) but are lower than the organic C levels of natural peat which may contain greater than 40% organic C. Since C is one component of organic matter, soil scientists generally multiply the organic C concentration by 1.74 to *estimate* organic matter percentages in the soil. Using this conversion, roughly 50% - 52% of the dry weight of the PFB material is organic matter (or 25% of the field fresh weight). Loss-on-ignition levels indicate 58% - 60% organic material and are considered to match closely, given heterogeneity of the sample and the fact that other organic compounds such as S compounds may be lost on ignition during analysis.

The 0-10 cm section of the background soil core has an organic carbon level of 2% and is considered representative of mineral soils. In the background subsoils, organic C drops to 0.7%. Organic C levels in the middle of the Sound-Sorb cores were 6.9% and 8.4%. The difference between the organic C in the fresh PFB and the Sound-Sorb is greater than the difference that would be obtained by the addition of mineral soil in an amount of 20% - 30% to form Sound-Sorb. This is likely due to the oxidation of organic matter by microorganisms. In the presence of high Ca and Mg, the CO₂ generated during the oxidation of organic matter would be available to form carbonate in the alkaline PFB material. While organic C levels decreased significantly, carbonate-C levels increased from a range of 1.5% - 1.9 % in the fresh PFB material to 2.7% - 2.9% in the berm. This is also consistent with the higher limestone content of the aggregate pit material used when making Sound-Sorb. The inorganic and organic carbon levels are not an environmental concern and therefore guidelines have not been developed.

Nitrogen (N) and Phosphorus (P)

Nitrogen and phosphorus are major plant nutrients and are of critical importance for plant growth. Nitrogen in plants was originally obtained from the atmosphere. The decay of vegetation results in the release of nitrogen which then undergoes microbial mineralization forming ammonium (NH_4) then nitrite (NO_2) and finally nitrate (NO_3). During the N cycle, nitrogen gas (N_2) and ammonia (NH_3) may be lost to the atmosphere. Nitrogen is a major nutrient and is taken up by plants as ammonium ions (NH_4^+) and nitrate ions (NO_3^-) and is recycled as organic N. Nitrate is also lost from the soil through leaching. Nitrogen tends to be high in decaying vegetation and levels of 6 mg/g are common in compost. In peat, concentrations of 10 - 20 mg/g occur. The background core surface sample contains 1.6 mg/g N and smaller amounts (0.6 mg/g) are found in the subsoil. The N levels in the fresh PFB material are low (1.8 mg/g to 2.5 mg/g) considering the high amount of organic matter, and N supplements may be needed to improve PFB decomposition in agricultural soils. The Sound-Sorb surface samples (0-10 cm) have higher total N levels (4.1 mg/g and 6.3 mg/g) than the middle part of the core and reflect the compost material placed on the surface of the berm. The organic C:total N ratios of the background soil are approximately 12:1 and the ratio in the PFB is close to 100:1. The ratios in Sound-Sorb are 19:1 and 32:1, with a high of 76:1 in a sample from core 3 at the base of the berm. These lowered ratios in the berm result mostly from a reduced amount of organic C in the Sound-Sorb berm, rather than from an increased amount of N in Sound-Sorb as compared to fresh PFB. Heterotrophic bacteria, using the C as a food source, tie up N during the decomposition process making it unavailable to nitrifying bacteria. Nitrogen fixation by bacteria was reported in the bioassay study of the PFB material (Ontario Ministry of the Environment, 1998). The limited amount of N in the PFB material may eventually be a rate determining step in halting the activity of the heterotrophic bacteria within the Sound-Sorb berm.

Phosphorus is contributed by minerals primarily through the weathering of apatites and by the decomposition of organic matter. The solubility of apatites is low, particularly fluorapatite, meaning that despite the presence of P in soils, it is often not available in sufficient amounts to plants. This results in the addition of large amounts of P fertilizers to agricultural soils each year. In acid soils, Fe and Al hydroxy phosphates are formed which are very insoluble, contributing to P deficiencies. Plants absorb most of their phosphate when it is in the orthophosphate form (H_2PO_4 and HPO_4^{2-}). At pH levels greater than 7.5, as occur in the berm, this P is mostly insoluble through its precipitation as mono- and di-calcium phosphates. Phosphorus levels in the PFB material, the Sound-Sorb berm and the background soil are low (< 1 mg/g).

Total Sulphur (S) and Extractable Sulphate (SO_4)

Minerals bearing sulphur tend to hold sulphur in the form of sulphide. Chemical weathering releases S, forming hydrogen sulphide (H_2S) which then oxidizes to sulphate (SO_4). The sulphate can be taken up by plants. Sulphate is also added directly to the soils in Ontario by strong acid precipitation. This is the result of large amounts of sulphur dioxide (SO_2) which are emitted to the atmosphere by the burning of fossil fuels. Decaying vegetation also releases S to the soil. Microbial oxidation of the S results in a number of intermediary products and finally SO_4 . Sulphate is generally stable except under reducing conditions where SO_4 -reducing bacteria use the

oxygen in the SO_4 to oxidize the organic matter, leaving S^{2-} . The resulting S^{2-} can quickly react with iron II (Fe^{2+}) in solution to precipitate iron sulphide (FeS). As a result of the oxidation processes of bacteria and the atmospheric deposition of SO_4 , high levels of extractable SO_4 can be found in the organic horizons of soils. Sulphate also adsorbs to the Fe and Al hydrous oxides present in the soil and levels of up to 400 $\mu\text{g/g}$ to 500 $\mu\text{g/g}$ of adsorbed SO_4 were found in forest sub-soils rich in these hydrous oxides in central Ontario (Neary et. al., 1987).

Total S in the Sound-Sorb material was in the 0.09% to 0.14% (900 - 1400 $\mu\text{g/g}$) range. For comparative purposes, as there is not a background OTR concentration for total S, the levels of S found in Sound-Sorb are similar to total S levels (0.09% - 0.11%) measured in surface horizons of central Ontario forest soils (Neary et. al. 1987). The background core surface sample had 0.02% total S.

Extractable SO_4 concentrations of 400 $\mu\text{g/g}$ to 930 $\mu\text{g/g}$ were found in the berm core. Sulphate was not measured in fresh Atlantic Packaging material but monthly data reported by Atlantic Packaging for 2000 show levels between 500 $\mu\text{g/g}$ and 1200 $\mu\text{g/g}$. Sulphate is prevalent in pulp and paper wastes as a result of the use of sulphite in the paper-making processes. There are no contaminated site guidelines for total S or SO_4 . Low levels were found in the sandy background mineral soil, although much higher levels can be found naturally in fine-textured soils. If conditions within the berm are anaerobic for periods each year, the potential exists for H_2S formation.

The aesthetic objective for SO_4 in drinking water is 500 mg/L (Ontario Ministry of the Environment, 2001). High levels may cause scale buildup, and levels above 150 mg/L may result in a noticeable taste, however, the human body adapts to the high levels (Ontario Ministry of the Environment, 2001). There is also an aesthetic objective for sulphide of 0.05 mg/L as H_2S (hydrogen sulphide). It is unlikely that harmful doses of sulphide in drinking water would be consumed because of the associated unpleasant taste and odour (Ontario Ministry of the Environment, 2001).

Cyanide (CN)

Cyanides are compounds composed of the group $\text{C}\equiv\text{N}$. Cyanides are present naturally in soils and are found in vitamin B_{12} and many foods we eat such as apricots, lima beans, peas, sweet potatoes, almonds and cassava root. Guideline levels for cyanide compounds are usually set for free cyanide, although total cyanide guidelines also exist in some jurisdictions. Free cyanides include HCN and CN^- . HCN is water soluble but is less dense than water and in soil and water it tends to eventually volatilize. Microbes also break down CN into carbon dioxide (CO_2) and ammonia (NH_3). At a pH of 8 or above, HCN dissociates to H^+ and CN^- and at a pH below 8 it remains a volatile acid (EPA, 1992). Total CN also includes less harmful compounds such as NaCN and KCN which are water soluble.

Cyanide transport in soil is controlled by volatilization of HCN which results in the rapid release

of CN from the soil, and by biodegradation which results in CN break down into harmless byproducts. Precipitation after complexing with heavy metals, such as Fe, is less important and ferrocyanides are photosensitive and break down in the presence of light (US EPA, 1992). Cyanides are not significantly adsorbed by clays.

The concentration of free rather than total cyanide is an environmental concern and for this reason the Table A contaminated site guideline for residential/parkland or agricultural land use in a potable groundwater situation is 100 µg/g of free cyanide. The Table F OTR for free cyanide in surface soils is low (0.12 µg/g). Cyanide was not measured on fresh Atlantic Packaging PFB material, but the Sound-Sorb material was analyzed. Total CN concentrations varied between 7.55 µg/g and 10.4 µg/g and were higher than the trace amounts found in the background soil. The three samples with total CN concentrations above trace amounts were then analyzed for free cyanide to compare with guideline concentrations. The concentrations found were 0.14 µg/g, 0.26 µg/g and 0.40 µg/g of free cyanide, less than the Table A contaminated site guidelines and slightly above Table F, OTR concentrations. The Regulation 347 toxicity leach test concentration for free CN is 20 mg/L, an amount which would not be obtained from Sound-Sorb. The Ontario drinking water standard for free cyanide is set at 0.2 mg/L and levels less than 10 mg/L are readily detoxified in the body to thiocyanate (Ontario Ministry of the Environment, 2001). The PWQO is set at 0.005 mg/L for free cyanide.

Bacteria

Bacteria makes up one fraction of the very diverse population of microorganisms found in soil. Along with fungi, actinomycetes, and significant populations of protozoa, nematodes and other soil fauna, bacteria perform important roles in the cycling of nutrients within the soil. Bacteria tend to occupy the upper layers of the soil where favourable temperature, moisture and nutrient conditions encourage growth. Each gram of surface soil can contain millions and even billions of bacteria when conditions are favourable. Bacteria may be heterotrophic or autotrophic. Heterotrophic bacteria predominate, deriving their energy from the carbon in the organic matter in the soil, while autotrophic bacteria rely on sulphur, iron, ammonium compounds and the carbon dioxide in the soil to survive. Bacteria are present in aerobic and anaerobic conditions throughout the normal pH range of soil (pH 3 to pH 9), although different types of bacteria require different environmental conditions to thrive.

Heterotrophic bacteria vigorously compete for food and it is the food supply that is often a limiting factor in sustaining the population. Consequently, the population may dramatically change in the soil very quickly. Certain types of bacteria can form spores which allow a dormant period when conditions are not favourable, only to thrive again once conditions improve.

Coliform Bacteria

Coliform bacteria are a group of heterotrophic, non-spore forming bacteria which live in both aerobic and microaerophilic conditions. Coliforms which have the ability to grow at an elevated temperature of 44.5° C are termed thermotolerant. Historically, all thermotolerant coliforms were

believed to have been derived from the gut of warm-blooded animals. More recent evidence indicates that some non-gut derived coliforms have the ability to also grow at the elevated temperature. Consequently, a distinction has been made between thermotolerant coliforms and *Escherichia coli* (*E. coli*), the indicator species of coliform which is widely recognized as being fecal in origin (fecal coliform).

Pulp and paper processes have long been known to produce liquid effluents and solid waste with high levels of thermotolerant, fecal indicator bacteria, although no fecal source is present in the process (Archibald, 1999). In the clarifier tanks, an elevated temperature of 40°C and the presence of sugars and other nutrients provide ideal conditions for bacterial growth. All new mill water used by the plant is chlorinated municipal water and all recycled water is treated with sodium hypochlorite. When necessary, the sludge is activated using freeze-dried non-pathogenic forms of bacteria and the water treatment on site is restricted to mill waste, with the sanitary sewers discharging directly into the city sewer system (Atlantic Packaging pers. com. 2001). Fecal streptococci, an enterococci bacteria, is also present in humans but in lower numbers than *E. coli*. Research has shown that fecal streptococci are also present in sludge from pulp and paper mill wastes and vegetable and fruit processing wastes (Gauthier and Archibald 2000). Published information suggests that the presence of non-intestinal fecal indicator bacteria in pulp and paper mill waste is attributed to biofilm formation on the process pipes. Another pathogenic bacteria species, salmonella, was not detected in pulp and paper mill waste (Gauthier and Archibald 2000).

The ability for a bacteria to act as a pathogen (i.e. to produce disease in humans) depends on the strain, not the species. For example, while some strains of *E. coli* are harmless, *E. coli* O157:H7 is a virulent pathogen. A study of seven pulp and paper mills in Ontario and Quebec found high levels of total coliform (10^6 - 10^8 cfu/g), fecal coliform (10^5 - 10^8 cfu/g) and enterococci (10^1 - 10^7 cfu/g) in combined primary and secondary clarifier de-watered paper mill biosolids (Gauthier and Archibald, 2000). Identification of the strains of *E. coli* showed that none of the 10 strains isolated were pathogenic (i.e. produced toxin genes) (Gauthier and Archibald, 2000). In this same study, it was reported that non-pathogenic fecal streptococci were present in levels ranging from 5,000 cfu/g to 8,000 cfu/g.

The U.S. Environmental Protection Agency (EPA) set a level of 2.0×10^6 cfu/g as the guideline for fecal coliform in Class B biosolids used for land application. Class B requirements include limited public access for up to six months and waiting periods for crop harvesting and animal grazing while natural environmental conditions reduce the coliform count. Ontario requires sewage biosolids to be stabilized and digested and recommends waiting periods before grazing or harvesting which vary from 3 to 12 months depending on the land use (Ontario Ministry of the Environment, 1996). For PFB application on farmland, the same waiting period restrictions would apply as for sewage biosolids. The *E. coli* concentrations, as a measure of fecal coliform in the fresh PFB material from Atlantic Packaging, ranged from 3.0×10^5 to 5.0×10^5 cfu/g dry weight. This is within the U.S. EPA guideline for Class B biosolids. Assuming no fecal coliform contribution from the addition of mineral soil added to Sound-Sorb, the *E. coli* levels in the Sound-Sorb berm should be lower. For samples taken in March 2001, Lakefield Research

reported concentrations of 1.1×10^3 cfu/g to 2.8×10^4 on berm samples from the OSGS (Lakefield Research, Certificate of Analysis, March 2001).

Results from MOE for the Sound-Sorb berm 17 months after construction, revealed *E. coli* and fecal streptococci levels of < 10 cfu/g, with the exception of one sample which had an *E. coli* count of approximately 100 cfu/g dry weight. These concentrations are below the U.S. EPA guideline of 1000 cfu/g for Class A biosolids. Even total coliform levels were three orders of magnitude lower than the total coliform levels of the fresh PFB material. It is possible that the virtual elimination of the fecal coliform were a result of limited N available for use during decomposition and the temperature fluctuations over the course of the berm's existence. A temperature of 127° C has been reported as the temperature known to effectively sterilize the soil and sterilization of soil for horticultural purposes is often done at 80-100°C (Flegmann and George, 1975). More recent studies of bacterial reduction in sewage biosolids with high solids content have found that a temperature of 70° C for a minimum of 30 minutes provides effective reduction (European Commission Directorate-General Environment, 2001). An internal berm temperature of 78°C was reported by Lakefield Research at a one foot depth in March, 2001 (Lakefield Research, Certificate of Analysis, March 2001). Reduction of the microorganism population at these temperatures may have slowed decomposition sufficiently to allow the berm to cool to the ambient temperatures found in the fall. The organic C concentrations in the berm have been reduced to less than half of what the predicted level would be in fresh Sound-Sorb at a 70:30 ratio of PFB:mineral soil, indicating significant bacterial activity. Rapid organic decomposition has also been reported in a bioassay study done on PFB in sandy loam soils (Ontario Ministry of the Environment, 1998). The low *E. coli* measurements obtained by MOE confirm the low levels found by Gartner Lee Ltd. in berm material sampled in June 2001. Gartner Lee Ltd. reported that *E. coli* concentrations were less than the detection limit and total coliform levels were 1400 and 9700 cfu/g (Gartner Lee Ltd., 2001). This evidence suggests that biological processes the PFB material within the berm significantly decreases the levels of bacteria.

The transport of *E. coli* through the soil overburden beneath the berm to the underlying groundwater is limited by depth to the water table, soil chemistry and temperature conditions, the presence of an organic substrate capable of providing a food supply in the mineral overburden at depth, and pore size and distribution which will affect the hydraulic conductivity. The hydrology assessment done by MOE in 2001, assumed a 50-day survival time for *E. coli* and calculated that the movement of bacteria in the groundwater would be 34 m under worst case conditions. Bacterial contamination of groundwater is most prevalent in conditions where there is a direct conduit from the surface to the groundwater such as areas of fractured bedrock and thin overburden, or in areas with improperly maintained wells, cracked well-casings, unsealed tile joints, improperly protected and raised well heads and in shallow wells which are under the influence of surface water.

In conclusion, research to date points to the non-pathogenic nature of fecal coliforms in paper mill wastes, the probability is low that coliform will survive the move from the surface through the soil to the groundwater, and analysis of the berm material suggests that fecal coliform is no longer present. Nevertheless, given the high *E. coli* levels in fresh PFB material and given the large

amount of material present in the berm, it is important to monitor groundwater and surface water draining the berm at the OSGS site.

Chloride (Cl)

Chlorine is an essential element for plants and occurs in the chloride form in soils as simple salts. Weathering of rocks and minerals yields large amounts of chloride and the world's oceans have become sinks for chloride. Chloride salts such as NaCl and KCl are readily soluble. Chloride is not adsorbed tightly and tends to move through the soil easily. In arid areas, chloride salts accumulate naturally but in humid temperate regions chloride levels are generally low in soils except in areas affected by road salting and fertilizer application.

Chloride is non-toxic but at high concentrations imparts a salty taste to the water which would discourage drinking the water. The aesthetic drinking water objective for Cl and the provincial water quality objective for Cl in lakes and rivers are both 250 mg/L. The typical range for uncontaminated parkland soil (OTR) is 330 µg/g of water-extractable Cl. Concentrations in fresh Atlantic Packaging PFB (130 µg/g to 140 µg/g) are lower than Table F, OTR levels, but levels in the Sound-Sorb berm are considerably higher (540 µg/g - 880 µg/g). As total chlorine in natural vegetation is present at the % level, the decomposition of the organic paper fibre material may have released Cl, causing higher levels of water extractable Cl in the berm than in the fresh PFB material. Contaminated soil guidelines for water-extractable Cl have not been developed. Monitoring of groundwater and surface water for Cl is important to provide information concerning the movement of Cl within the berm.

Volatile Organic Compounds

The laboratory reported on a large number of volatile organic compounds, however, only a few were above the detection limit. 1,4 dichlorobenzene is present in moth repellent and its use in toilet deodorizers means that has been measured in sewage biosolids. It is not expected in paper fibre sludge and the 1998 and 2001 data show that it is below the 10 ng/g detection limit in both fresh PFB material and Sound-Sorb. Discussions which follow focus only on compounds which were found at levels above the detection limit. Concern has been raised by members of the public about the possible presence of methyl ethyl ketones in the PFB. These were not detected in either fresh PFB or the Sound Sorb berm cores. Trace amounts of paraffinic and naphthenic organics were detected in two of the berm samples.

Toluene (methylbenzene)

Toluene is a monocyclic aromatic hydrocarbon which is used in paint thinners, rubbers, ink solvents, fuels and in a variety of consumer products such as nail polish remover. Toluene in the environment occurs primarily as direct releases to the atmosphere from the burning of gasoline. Small amounts are released directly in industrial waste water. Toluene in the soil atmosphere and water near the surface volatilizes to air where it is degraded through reaction with hydroxyl

radicals. Toluene remaining in the subsoil is subject to microbial degradation by microorganisms such as *pseudomonas* which, through a number of intermediate steps, releases the carbon from the organic compounds. This can occur in both aerobic and anaerobic conditions. Toluene is also moderately soluble and can be transmitted through the soil to the groundwater. Once in the groundwater, toluene is slowly degraded.

The Ontario drinking water standard for toluene is 24 µg/L and is not health related but an aesthetic objective. Levels above this can impart a distinct taste to the water (Ontario Ministry of the Environment, 2001). PWQO guidelines are set at 0.8 µg/L for the protection of lakes and rivers, although fish avoidance occurs at levels of 2 mg/L and toxicity symptoms in aquatic organisms are generally not seen until higher levels (International Program on Chemical Safety, 1985).

Toluene levels in the background soil core sample were less than the 10 ng/g detection limit. Toluene in fresh Atlantic Packaging PFB material ranged from 190 ng/g to 350 ng/g dry weight. Toluene guidelines for biosolids which are applied to agricultural land have not been developed, however, Sweden uses a guideline of 5 µg/g (5000 ng/g) (Harrison et al, 1999).

In the Sound-Sorb berm cores, toluene was found only at the lower depths in two samples. Concentrations were 140 ng/g at 80 cm and 33 ng/g at a 24 cm depth, higher than the Table F OTR for toluene (2 ng/g). The contaminated site Table A guideline for soils in residential/parkland land use in a potable groundwater situation is 2.1 µg/g (2100 ng/g) and federal soil quality criteria are set at 800 ng/g (CCME, 1997). Although below Table A contaminated site guideline levels, toluene should be included in well water testing at the berm site to ensure that it is not moving through the soil below the berm.

Xylenes (1,2 methylbenzene, 1,3 methylbenzene and 1,4 methylbenzene)

Xylenes are also monocyclic aromatic hydrocarbon compounds. There are three isomers of xylene: *ortho*-, *meta*- and *para*- which are referred to as o-xylene, m-xylene and p-xylene. Since the *m* and *p*- xylenes are not separated during analysis these are reported together and *o*-xylene is reported separately.

Xylenes are used as octane enhancers in gasoline, occur naturally in minor amounts in petroleum and are used in industrial solvents, in dyes and household paints and cleaners. Xylenes are not prevalent in drinking water and surface water, but are emitted to the air in large amounts as a result of automobile exhaust. Xylene emissions are decreasing as better technology reduces volatile organic compound emissions from automobiles.

Xylenes are volatilized rapidly from surface water and the surface of soils. The moderate solubility of xylenes means that they have the potential to move to the groundwater. Xylenes are not expected to be oxidized, photolyzed or hydrolyzed to any great extent in soils (CEPA, 1993). Like toluene, xylenes are biodegraded by microorganisms in the soil in both aerobic and anaerobic conditions, but once in the groundwater xylenes biodegrade slowly.

Concentrations of total xylene in the fresh paper fibre biosolids are between 200 and 530 ng/g dry weight. The contaminated site Table A guideline for total xylene in residential/parkland in a potable groundwater situation is 25 µg/g (25000 ng/g). Xylenes were not detected in the Sound-Sorb samples. A health-related drinking water standard has not been set for xylene, as toxicity is low, but an odour-related aesthetic standard has been set at 0.3 mg/L (300 µg/L) (Ontario Ministry of the Environment, 2001). Aquatic toxicity is low, usually in the low mg/L level but, for protection of the most sensitive organisms, levels of 2, 30 and 40 µg/L are set for *m*-, *o*-, and *p*-xylenes respectively. Although below the Table A contaminated site guideline level, the concentration in the fresh material is higher than the background Table F, OTR concentration and xylenes should be included in the testing done on wells at the OSGC site.

Ethylbenzene

Ethylbenzene is an additive in gasoline, and is used to make styrene which is used in many plastics. It is also used in making rubber and plastic wrap. Ethylbenzene is volatile and is lost to the atmosphere quickly from the surface of soils and waters. It binds only moderately to sediment and soil, therefore, if it is present at depth in the soil it has the potential to move to the groundwater. The Table F, OTR for ethylbenzene is 2 ng/g and the Table A contaminated site guideline is 280 ng/g. Ethylbenzene was found at a level of 70 ng/g in the fresh Atlantic Packaging PFB. It was not detected in the berm samples. The aesthetic Ontario drinking water objective for ethylbenzene is 0.24 µg/L. The PWQO is 8 µg/L. Ethylbenzene should also be included in a volatile scan of the test well samples.

Dioxins and Furans

“Dioxins and furans” refers to a group of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzo-furans (PCDF). Chemically and toxicologically the two groups are closely related. Together the group is comprised of 210 congeners which differ in their placement of the chlorine atoms. Toxicities of the various congeners range from non-toxic to the most toxic compound known. Seventeen of the 210, which contain chlorine in the 2,3,7,8 positions are considered the most toxic. To determine the toxicity in a sample containing a mixture of PCDD/F congeners of differing toxicities, the concentrations for the different congeners are normalized by expressing the results relative to the most toxic form of dioxin, 2,3,7,8 tetrachlorodibenzo-*p*-dioxin (TCDD). The results for each of the 17 congeners are expressed as 2,3,7,8 TCDD toxic equivalents, and the results are summed to obtain a TEQ (toxic equivalent quantity) for the sample.

Dioxins and furans are created in thermal processes and are byproducts of wood and fuel burning, waste incineration, chlorinated chemical production, pulp and paper production and natural occurrences such as volcanoes and forest fires. Pulp and paper industries have significantly reduced TCDD/F in their effluent over the past two decades (CCME, 2001). TCDD/Fs are persistent in the soil, as they are strongly adsorbed and insoluble. There is only slight degradation by microorganisms. Dated sediment cores from remote lakes in Scotland, the Arctic and Finland have shown that TCDD/F concentrations increased from background levels of between 1 pg

TEQ/g and 5 pg TEQ/g before 1940 to peak levels between the 1950's and the 1970's (UK DETR, 1999). With awareness of their toxicity, levels have been falling since the 1980's (UK DETR, 1999). Contaminated sites in the vicinity of stack emissions can reach thousands of pgTEQ/g.

The TCDD/F toxic equivalent quantity in the fresh PFB material was 3.16 pgTEQ/g. The Sound-Sorb sample had a TEQ of 2.81 pgTEQ/g and the background soil core at the 42 cm depth had a TCDD/F TEQ of 1.55 pgTEQ/g. Atlantic Packaging is required to measure TCDD/F in their biosolids, and for 2000 the level reported was 3.09 pgTEQ/g. The Table F, OTR level for dioxin/furans in surface soil is 7 pgTEQ/g. Dioxins/furans in the PFB and Sound-Sorb are present at levels close to background, and less than the Table F, OTR for uncontaminated soils.

Acrylamide Monomer

Acrylamide monomer is used to produce polyacrylamides. A small amount of residual acrylamide monomer occurs in the polyacrylamide. Polyacrylamides (PAM) are high molecular weight, long chain polymers. Polyacrylamides are used extensively as flocculants in the pulp and paper industry, in water treatment systems and in the food processing industry. In pulp and paper mills, the polymer is used to bridge the paper fibre and clay particles into large flocs which settle to the bottom of the tank. PAMs are approved by the United States Food and Drug Administration and the United States Environmental Protection Agency (USEPA) for use in food processing and water treatment systems, but the polymer used must be determined to contain less than 0.05% residual acrylamide monomer (Sojka and Lentz, 1994). PAMs have been used as soil conditioners, as slope stabilizers and for erosion control since World War II. PAMs have a strong affinity to bind to organic and clay colloids. Two kinds of PAMs exist, anionic and cationic. Cationic PAMs can be toxic to fish at very high levels by binding to the gills causing suffocation (Barvenik, 1994).

Polyacrylamide has not been shown to break down into acrylamide monomer under laboratory conditions. Studies have shown that polyacrylamides biodegrade as microorganisms use the amide groups as sources of nitrogen (Sojka and Lentz, 1994). Grula et al (1994), however, found that cationic polymers of the type used by Atlantic Packaging did not support any of three strains of *pseudomonas* bacteria, which for other PAMs were shown to biodegrade the polyacrylamide. Recent work by Chang et al (in press) studied cationic polyacrylamide degradation under both aerobic and anaerobic conditions. These authors demonstrated that partial degradation of polyacrylamide occurred, as measured by changes in the BOD₅ of a polymer solution under aerobic conditions and as measured by gas release under anaerobic conditions. In aerobic conditions, oxygen consumption was consistent with calculated stoichiometries of partial degradation resulting in trimethylamine and polyacrylic acid. Trimethylamine is the same volatile gas produced by rotting fish. In anaerobic conditions the partially degraded portion was completely degraded (Chang et al. in press). The nondegraded portion remaining under both conditions left the acrylamide and acrylate monomers within the main polymer chain (Chang et al. in press), (i.e. acrylamide monomer did not exist as a separate entity). The remaining polymer chain did not further degrade. This work supplements suggestions by Kay-Shoemake et al

(1998a,b) that the $[-CH_2-]$ backbone of the PAM was not degraded but that a polyacrylic acid polymer of the same length results, having a molecular weight of between 3,000 and 5,000.

Residual acrylamide monomer present in the polyacrylamide flocculant itself as a result of manufacturing the polymer, will partition primarily with the effluent water in the settling tank and not with the sediment. Any acrylamide monomer which does remain in the dewatered biosolids, however, will be mobile. Acrylamide monomer quickly polymerizes in the presence of light, at high temperatures (84° C or above) and studies have shown acrylamide monomer to biodegrade to harmless compounds within hours and days (Sojka and Lentz, 1994). Concentrations of 500 µg/g acrylamide monomer were shown to degrade to less than the detection limit in 5 days incubation at 30°C (Shanker et al 1990). Degradation results from the ability of aerobic bacteria to use the monomer as a source of carbon.

As the measurement of acrylamide monomer is not a routine test performed by the MOE Laboratory Services Branch, an experimental method was developed by the laboratory to test the PFB and berm samples. Only one sample of fresh Atlantic Packaging PFB was tested for acrylamide monomer and it was found at a concentration of 0.009 µg/g (9 ng/g) dry weight. All berm samples were tested and it was detected in only one of the samples at a level of 0.00036 µg/g (0.36 ng/g) dry weight. It was not measured in the background soil core. Few guidelines exist for acrylamide monomer, but the World Health Organization recommends that a guideline limit associated with a 10^{-5} cancer risk is 0.5 µg/L, Australia uses 0.2 µg/L and the U.S. EPA uses a water treatment operational guideline which states that the acrylamide monomer concentration of the polymer used in dosing the treatment system with polyacrylamide at 1 mg/L, does not exceed 0.05% (U.S. EPA, 2002). The concentrations found in the PFB material and in only one of the berm samples are low and are likely residual monomer present in the polymer itself. Degradation of the polymer to acrylamide monomer is not expected to occur. Nevertheless, testing of the groundwater wells at the gun club for acrylamide monomer should be performed.

***m*-Cresol, *o*-Cresol and *p*-Cresol (2-methylphenol, 3-methylphenol, 4-methylphenol)**

Cresols have been mentioned by members of the public as possible contaminants in the paper fibre biosolids. Cresols are methylphenols which are semi-volatile compounds derived from coal tar and which are used as wood preservatives. An organic compound identification screen did not detect cresols and therefore further target testing for these compounds was not done. Contaminated site guidelines have not been developed for cresols and Regulation 347 leachate quality criteria for *o*-, *m*- and *p*- cresols are 200 mg/L. The PWQO concentration for cresols is 1 µg/L.

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons are fused ring compounds given off whenever fossil fuels or wood are burned. As a result of combustion processes, atmospheric deposition is a source of PAH in uncontaminated soils. PAHs are also produced during waste incineration and can enter water and soil with runoff from the asphalt on roads and highways or in the effluent from

petroleum refining industries. Volcanoes and forest fires are natural sources of PAHs. The less efficient the burning process, the more PAHs are emitted. PAHs tend to be tightly held in soils by the organic and clay colloids and may persist in soils for years, so that concentrations in soils are orders of magnitude higher than water. PAHs are not taken up by plants and are not susceptible to leaching.

PAHs attach themselves rapidly and completely to the humus fraction of the soil (U.S. EPA, 1997) and microbial degradation is an important mechanism for removing PAHs from soil. The microbial degradation consumes oxygen and contributes to anaerobic conditions which provide favourable conditions for sulphate-reducing bacteria. It has been shown, however, that disruption of the benzene ring in the PAH compounds naphthalene, anthracene, phenanthrene, fluorene, fluoranthene and pyrene continues under anaerobic conditions as well in the presence of denitrification and sulphate-reducing bacteria (Karthikeyan and Bhandari, 2001). All PAH compounds were detected at background levels, below the Table F, OTR for uncontaminated soils in Ontario (Table 4).

Chlorophenols

Chlorophenols are monocyclic aromatic compounds which have been used for many years as wood preservatives and as herbicides, disinfectants and defoliants. Residues tend to remain in the environment. Biodegradation of chlorophenols occurs under oxidizing conditions and has been used as a method for the remediation of chlorophenol-contaminated soil. Sulphate-reducing bacteria also biodegrade chlorophenols in reducing environments. Pentachlorophenol is considered the most toxic. Pentachlorophenol, tri- and tetrachlorophenol have been reported in paper mill waste. In recent years, better technology and the dechlorination of phenolic compounds by microbial digestion have significantly decreased the concentrations of chlorophenol compounds in pulp and paper wastes. Chlorophenols were analysed on Atlantic Packaging PFB material in 1998 and were not repeated in this study. Pentachlorophenol was the only chlorophenol detected in the 1998 tests and occurred at a level of 0.015 µg/g, an order of magnitude lower than the background Table F OTR (0.1 µg/g) and lower than the Table A contaminated site guideline level of 5 µg/g. Ontario drinking water standards for pentachlorophenol are 60 µg/L.

Polychlorinated Biphenyls (PCBs)

PCBs are used in hydraulic fluids, electrical transformers, plasticizers and adhesives. PCBs are known carcinogens and biomagnify in the environment as they transfer into the fatty tissue of mammals. PCBs are persistent pollutants and can only be destroyed by high temperature incineration. Their use is currently being phased out. The concentration measured in 1998 in fresh Atlantic Packaging PFB was 0.08 µg/g, considerably lower than the Table F OTR of 0.3 µg/g and lower than the Table A contaminated site guideline of 3 µg/g. The Ontario drinking water standard is 3 µg/L. PCBs were not measured again in this study.

Nonylphenol ethoxylates

Nonylphenol ethoxylates are polyphenol polyethoxylates and have been used as surfactants since the 1940's (Brecher, 1998). Nonylphenol ethoxylates are widely used as nonionic surfactants and are discharged by sewage treatment plants in amounts which vary with the efficiency of the treatment system (Maguire, 1999). In the natural environment, the various ethoxylates degrade to nonylphenol which is moderately persistent in soils and groundwater, and more toxic than the higher ethoxylates. Guidelines do not exist in Canada, but nonylphenol ethoxylates are currently under review by the Canadian Environmental Protection Agency and the Ontario Ministry of the Environment and Energy. Research on the presence of these surfactants in fish from the Great Lakes is also currently in progress (USGS, 2000). Tests done on fresh Atlantic Packaging PFB was done in 1998 by the ministry laboratory using an experimental method. Levels were shown to be below the detection limit. Gartner Lee Ltd. also reported levels less than the detection limit in leachate from the OSGS berm in July, 2001. Further analysis was not done. Future analysis may be done when toxicity information and guidelines have been developed.

Total Petroleum Hydrocarbons (TPH)

Petroleum hydrocarbons are mixtures of organic compounds which are originally derived from geological substances such as oil and coal. They consist of complex mixtures of carbon and hydrogen with minor amounts of sulphur, oxygen and nitrogen. Carbon and hydrogen bond to create a large variety of compounds with varying molecular weights and properties. Examples of light molecular weight aromatic hydrocarbons are toluene, benzene, xylenes and ethylbenzene. These are volatile, were targeted for measurement separately and results are discussed under Volatile Organics. Similarly, polycyclic aromatic hydrocarbons such as naphthalene, pyrene, phenanthrene and benzo[a]pyrene were targeted for measurement separately and results are discussed under the section Polycyclic Aromatic Hydrocarbons. Petroleum hydrocarbons behave differently in the soil depending on their molecular weight and properties. Generally the lighter hydrocarbons tend to be the most mobile and the heavier hydrocarbons (C17 - C50) are persistent and do not leach from the soil. Hydrocarbons are degraded by bacteria under aerobic and anaerobic conditions within the soil, and bioremediation is often used to aid in the clean-up of hydrocarbon-contaminated sites. The contaminated site guidelines for petroleum hydrocarbons reflect the risk associated with movement of the hydrocarbons through the soil. Petroleum hydrocarbons may create odour and taste problems in the environment.

Owing to the complexity of the testing, total petroleum hydrocarbon (TPH) levels were measured on only one of the Sound-Sorb berm samples. The Sound-Sorb sample analyzed has a TPH concentration of 3400 µg/g which is comprised of a complex mixture of hydrocarbons, primarily in the C16 to C50 range (chain molecules with between 16 carbon atoms and 50 carbon atoms). Only trace levels of TPH compounds were found in the C <16 range. The mass spectrometry organic screen identified these heavier hydrocarbons as primarily *n*-alkane (straight chain) hydrocarbons. Alkanes are aliphatic hydrocarbons containing single carbon-carbon bonds.

Aliphatic compounds tend to be less water soluble and more volatile than aromatic compounds, and are readily biodegraded in soil by bacteria. The TPH concentration of 3400 µg/g exceeds the Ontario Table A contaminated site guideline of 1000 µg/g for heavy hydrocarbons (C16 - 50). The guideline concentration for lighter hydrocarbons is 100 µg/g, but only a trace amount of the measured concentration of 3400 µg/g were light hydrocarbons (C < 16). The Canadian Council of Ministers of the Environment (CCME) proposed Canada wide standards for TPH which are grouped into four categories. The proposed guideline for the lighter C6 - C17 petroleum hydrocarbons (groups F1 and F2) in coarse textured soils is 180 µg/g and the proposed guideline is 3200 µg/g for heavier C >17 hydrocarbons (groups F3 and F4). For fine textured material (median grain size less than or equal to 75 µm) such as the Sound-Sorb berm, the proposed CCME guidelines are 1160 µg/g for C6 - C17 and 6400 µg/g for C >17 hydrocarbons (CCME, 2001).

The total TPH concentration of 3400 µg/g (C16 >50 range) found in the Sound-Sorb sample is higher than Ontario's heavy hydrocarbon Table A guideline (1000 µg/g), slightly higher than the proposed CCME guideline for coarse textured soil (3200 µg/g) and lower than the proposed CCME guideline for fine textured material (6400 µg/g). The berm material itself would be considered fine-textured based on the amount of clay in the material. The petroleum hydrocarbons in the PFB material are likely derived from the petroleum distillate-based products used in the settling tank, however, given the nature of the extraction method used, organic compounds present in the paper fibre material itself likely also contribute to the TPH measurement. Indeed, tests on uncontaminated, organic surface soils in the past have yielded TPH concentrations in the thousands of µg/g (Standards Development Branch, MOE, pers. com. 2002).

The heavier hydrocarbons tend to persist in the berm rather than leach, and are subject to biodegradation. Nevertheless, it should be determined whether or not the product is having an adverse effect on the environment. The Ministry's contaminated site guidelines, as discussed earlier, are intended for use on the soils underlying, or in the vicinity of, the product thought to be causing the contamination, not for comparison to concentrations in the foreign material itself. For this reason, and because the product itself is subject to decomposition *in situ*, a site-specific risk assessment is recommended to determine the potential environmental risk associated with the presence of petroleum hydrocarbons in the berm. Further testing of fresh PFB material should also be undertaken.

CONCLUSIONS

Fresh Atlantic Packaging Biosolids

Parameters measured in the fresh PFB material were lower than all the present and long range target provincial guideline levels for biosolids which are applied to agricultural land. We also tested the fresh PFB for other elements and compounds not listed in the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land, 1996*. The concentrations of these elements and compounds were compared to the background concentration range typical of uncontaminated Ontario surface soils (OTR-Table F and OTR98). Toluene, xylenes and ethylbenzene exceeded the Table F concentrations of the background range of typical Ontario soils (OTR). Biosolids guidelines are generally higher than OTR levels to take into account the allowable application rate and dilution of biosolids into the soil on the agricultural field. Ontario does not have biosolid guideline levels for these compounds, but, as noted in the discussion, toluene levels were below the guideline level used in Sweden for biosolids which are applied to farmland. Since we do not have a biosolid guideline for toluene, xylene and ethylbenzene and since levels exceed the Table F, OTR concentrations, it is recommended that volatile organic compounds be measured in the soil and groundwater on sites which have received PFB application.

Sodium and copper concentrations, were above the Table F, OTR values, but were below concentrations listed in the *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Land, 1996*. Total petroleum hydrocarbons (TPH) and free cyanide were not measured on the fresh PFB but, based on testing of the Sound-Sorb, future testing will include these parameters.

For fecal coliform bacteria, concentrations were lower than the United States Environmental Protection Agency guideline for Class B biosolids used for application to farmland. Class B specifies waiting periods after application for harvesting and public access. Published evidence to date indicates that the *E.coli* and fecal streptococci present in the samples are non-pathogenic.

Sound-Sorb

With the exception of TPH, the concentrations of contaminants in the Sound-Sorb berm at the Oshawa Skeet and Gun Club were below the Ontario Table A, contaminated site guidelines and all but toluene, free cyanide and chloride were present in concentrations lower than the Table F, OTR or the OTR98 guideline for uncontaminated soils in Ontario.

Given the large component of organic matter in Sound-Sorb, the berm is subject to the same biological processes that occur in a naturally organic soil. Furthermore, the amount of clay and organic matter in the material, provide the prerequisites for the centre of the berm to become anaerobic during wet periods of the year. The anaerobic conditions may facilitate the movement of some elements, such as iron, promote the activity of sulphate-reducing bacteria and generate

hydrogen sulphide and methane. To continue to assess if there is any movement of elements and compounds through the berm, testing for a full suite of parameters should be done on groundwater and surface water in the immediate vicinity of the berm at the Oshawa Skeet and Gun Club.

Total petroleum hydrocarbon levels were measured only in the Sound-Sorb berm material (3400 µg/g) and were identified to be primarily in the C16 - C50 range. This is higher than the Ontario Table A, contaminated site guideline (1100 µg/g) for heavy hydrocarbons, slightly higher than the proposed CCME guideline for heavy hydrocarbons in coarse textured soil (TPH, C > 17 = 3200 µg/g) and lower than the proposed CCME guideline for heavy hydrocarbon compounds in fine textured material (6400 µg/g). The large amount of clay present in the berm material classifies it as fine-textured. Movement of petroleum hydrocarbons within the berm and underlying soil is probably limited. There is also previous evidence to suggest that large amounts of natural organic material can result in inflated TPH measurements, due to the extraction of natural organic compounds containing carbon during analysis. Keeping in mind that the contaminated site guidelines are for use on underlying and surrounding soil, not on the construction materials themselves, any potential for movement of the hydrocarbons out of the berm should be addressed through a site specific risk assessment.

Vigorous microbial activity has occurred within the Sound-Sorb berm, as seen in the reduction of organic C levels within the berm and the resulting high temperatures (78° C) measured by Lakefield Research. Fecal coliform were less than the detection limit when MOE sampled in November 2001, and were also not present in July 2001 when Gartner Lee Ltd. sampled the berm material. This is below the United States Environmental Protection Agency guideline for Class A biosolids (no waiting periods). Despite this, it is recommended that monitoring take place for fecal coliform bacteria in the surface and groundwater at the OSGS site.

For elements and compounds for which leachate quality criteria are provided in Regulation 347, the total amounts present are low enough that leaching from the PFB material is unlikely to yield leachate concentrations above the regulation criteria. Nevertheless, continued testing of the material will include an Regulation 347 toxicity characteristics leachate procedure.

THE NEXT STEPS:

The concentrations of elements and compounds measured in the berm are lower than Table A contaminated site guideline levels for all but TPH. All parameters but toluene, free cyanide and chloride in the berm were also lower than the Table F, OTR and the OTR98 range of Ontario soils. For contaminant concentrations in the berm which exceed Table F, OTR levels, movement of the contaminants into the surrounding environment should be addressed. Given the complexity of modeling chemical transport in the berm material and in the unsaturated zone of soil, the following are recommended:

1. Sound-Sorb berm sampling indicated free cyanide levels below the Table A contaminated site

guidelines but slightly above the Table F background OTR concentration. The fresh PFB material was not analysed for CN. The ministry recommends that MOEE and Atlantic Packaging measure free cyanide in fresh PFB to collect data on the free cyanide variability of the biosolids.

The results of this additional analysis should be tabled for consideration in the future management of Sound-Sorb.

2. Test wells should be installed at the berm site to address groundwater movement in the area. These wells, as well as surface water drainage, should be tested, by the ministry, for the full suite of parameters measured in this study, under a range of hydrological conditions.
3. Although published literature provides evidence that the *E. coli* in pulp and paper waste is non-pathogenic, and although biological processes reduced *E. coli* in the Oshawa Skeet and Gun Club berm to a level below the detection limit, fecal coliform should be monitored in the test wells.

The ministry is further pursuing the investigation of bacterial activity in paper fibre biosolids and Sound-Sorb through a contract to investigate the potential for and the generation of bioaerosols (bacteria and fungal spores) by the PFB material.

4. A site specific risk assessment (SSRA) should be conducted at the site of the OSGS berm to determine the risk associated with the TPH concentration found in the berm.

APPENDIX I

METHODS USED BY THE LABORATORY SERVICES BRANCH (LSB), MINISTRY OF THE ENVIRONMENT AND ENERGY FOR THE ANALYSIS OF SAMPLES

Solids, Loss on Ignition:

Determination by weight before and after low temperature oven drying to determine moisture loss, followed by weight loss on ignition of sample at 550° C for 4 h. (LSB method E3071)

pH:

Measurement of pH in PFB potentiometrically in a saturated paste distilled water extract (LSB method E9000)

Measurement of pH in soil potentiometrically in a 2:1 soil:solution ratio of 0.01M CaCl₂. (LSB method E3137)

Mercury:

Concentrated nitric/hydrochloric acid digestion in the presence of permanganate and measurement by cold vapour flameless atomic absorption spectrophotometry. (LSB method E3058).

Arsenic and Selenium:

Concentrated nitric/sulphuric/perchloric digestion, measurement by hydride generation flameless atomic absorption spectrophotometry. (LSB method E3091).

Aluminum, Barium, Beryllium, Cadmium, Calcium, Cobalt, Chromium Copper, Iron, Magnesium, Manganese, Molybdenum, Nickel, Silver Strontium, Titanium, Vanadium, Zinc:

Concentrated nitric/hydrochloric acid digestion, measurement by inductively coupled plasma atomic emission spectroscopy. (LSB method E3071 for PFBs, method E3071 for soils).

Sodium and Potassium:

Concentrated nitric/hydrochloric acid digestion. measurement by flame atomic absorption spectrophotometry. (LSB method E3075).

Cyanide:

Total and free cyanide are extracted at pH 12 for 10 - 16 hours. Total cyanide is measured after distillation and UV digestion colourimetrically. Free cyanide is measured similarly without the UV digestion. (LSB method E3015).

Nitrogen and Phosphorus:

Total Kjeldahl nitrogen digestion (sulphuric acid/persulphate), measurement by colourimetry. (LSB method E3116).

Carbon and Sulphur:

Total carbon and sulphur measured by LECO induction furnace and the production and measurement of CO₂ and SO₂ (LSB method E3012 for carbon, LSB method E3096 for PFBs).

Organic carbon is expressed as the difference between total C as measured above and inorganic C as measured by soil reaction with HCl and coulometric titration to measure CO₂ produced. (LSB method E3012).

Water Extractable Sulphate and Chloride:

The sample was shaken with distilled water for one hour at a 1:10 soil:solution ratio. Extracts were membrane filtered and chloride and sulphate were measured by suppressor column liquid ion chromatography (LSB method E3013).

Volatile Organic Compounds:

Volatile organohalides and hydrocarbons are analyzed in a headspace vial by gas chromatography with FID/ECD detection and MSD confirmation. (LSB method E3254).

Dioxin and Furans:

Soxhlet extraction and measurement of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans by high resolution isotope dilution gas chromatography-mass spectrometry. (LSB method E3418).

Chlorophenols and Phenoxyherbicides:

Solid/liquid extraction and measurement by gas chromatography/mass spectrometry (LSB method E3353).

Polynuclear Aromatic Hydrocarbons:

Extraction with hexane/acetone/dichloromethane and measurement by gas chromatography/mass spectrometry (LSB method E3350).

Nonylphenol and Ethoxylates:

Experimental method using dichloromethane Soxhlet extraction, gas chromatography-mass spectrometry and liquid chromatography-ultra violet (absorption) detection.

Total Petroleum Hydrocarbons:

Extraction with hexane/acetone followed by head space gas chromatography with flame ionization detection (LSB method E3397).

Acrylamide Monomer:

Water extraction of sample with shaking and ultrasonification, Ambersorb extraction followed by ethyl acetate extraction of acrylamide monomer and measurement by liquid chromatography-mass spectrometry. (an experimental LSB method).

APPENDIX II UNITS OF REPORTING

Solid Samples

$\mu\text{g/g} = \text{mg/kg} = \text{parts per million (ppm)}$

$\text{ng/g} = \mu\text{g/kg} = \text{parts per billion (ppb)}$

$\text{pg/g} = \text{ng/kg} = \text{parts per trillion (ppt)}$

$\text{mg/g} = \text{parts per thousand}$

$10,000 \mu\text{g/g} = 10 \text{ mg/g} = 1\%$

$\text{cfu/g} = \text{colony-forming units per gram}$

Liquid Samples

$\text{mg/L} = \text{parts per million (ppm)} = \mu\text{g/mL}$

$\mu\text{g/L} = \text{parts per billion (ppb)} = \text{ng/mL}$

$\text{ng/L} = \text{parts per trillion (ppt)} = \text{pg/mL}$

$\text{pg/L} = \text{parts per quadrillion (ppq)}$

$\text{Bq/L} = \text{becquerels per litre} = \text{a unit of radioactivity which expresses the rate of disintegration of a radio nuclide; one becquerel} = \text{one nuclear transformation per second and equals approximately } 27 \text{ picocuries.}$

APPENDIX III
TESTING REQUIRED IN 1999 CERTIFICATE OF APPROVAL ISSUED TO
ATLANTIC PACKAGING LTD./ COURTICE AUTO WRECKERS LTD.

Biosolids Monitoring:

Monthly	Quarterly	Semi-Annually
total suspended solids	chromium	arsenic
total organic carbon	cobalt	cadmium
total Kjeldahl nitrogen	copper	mercury
ammonia	molybdenum	selenium
chloride	nickel	phenol
sulphate	lead	
calcium (total/soluble)	zinc	
magnesium (total/soluble)	dioxins/furans	
sodium (total/soluble)		
pH		
phosphorus		
potassium		
boron		

Soil Monitoring:

pH
Total organic carbon
Phosphorus (sodium bicarbonate extractable) and total
Potassium
Calcium
Magnesium
Sodium
Copper

Sodium adsorption ratio (SAR)
Cation exchange capacity (CEC)
Arsenic
Boron
Cadmium
Chromium
Cobalt
Mercury

Soil Monitoring cont'd:

Molybdenum

Nickel

Lead
Zinc

Selenium
Dioxins/furans

Groundwater Monitoring:

pH
Nitrate
Sulphate
Total Kjeldahl Nitrogen
Total dissolved solids
Magnesium
Arsenic
Cobalt
Copper
Nickel
Molybdenum
Zinc

Conductivity
Chloride
Alkalinity
Ammonia
Calcium
Sodium
Cadmium
Chromium
Mercury
Lead
Selenium

Surface Water Monitoring:

pH
Nitrate
Total Kjeldahl Nitrogen
Suspended solids
Chemical oxygen demand (COD)
Cadmium
Chromium
Mercury
Lead
Selenium

Conductivity
Ammonia
Total Phosphorus
Biochemical oxygen demand (BOD)
Arsenic
Cobalt
Copper
Nickel
Molybdenum
Zinc

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TABLE 1. ATLANTIC PACKAGING PAPER FIBRE SLUDGE - WHITBY PLANT BUNKER (sampled Oct. 23/01)

Parameter	Units of Measurement	2001 MOE lab Sample 1 result value qualifier	2001 MOE lab Sample 2 result value qualifier	2001 MOE lab Sample 3 result value qualifier	2001 MOE lab Sample 4 result value qualifier	1998 MOE Analysis of Atlantic PFB Whitby Plant	2000 Atlantic Packaging Report mean concentrations	Table A Contaminated Site Criteria for recreational/ residential land use	Table F Typical Ontario Range of Background Soil Concentrations	Compost Guidelines	Biosolids Guidelines Allowable Metal Concentration in Biosolids	(long term target)
Solids	%	43	43	43	47	52						
Total ash	%	38	38	41	42	35						
Loss-on-ignition	%	62	62	59	58	65						
pH		7.7	7.7	7.7	7.5	na	7.5					
Arsenic	ug/g dry wt	0.72	0.74	0.63	0.55	1.2	0.75	20	17	10	170	35
Selenium	ug/g dry wt	0.081	0.070	0.047	0.074	<0.2	<1.0	10	1.9	2	34	6
Mercury	ug/g dry wt	0.05 T	0.05 T	0.05 T	0.05 T	na	0.03	10	0.23	0.15	11	1.4
Aluminum	ug/g dry wt	3540	4000	4860	4360	7200			30,000 OTF85 not in Table **	no value		
Barium	ug/g dry wt	35	38	43	31	38		750	210	no value		
Beryllium	ug/g dry wt	<0.2 <MDL	<0.2 <MDL	<0.2 <MDL	<0.2 <MDL	<0.5	0.1	1.2	1.2	no value		
Calcium	ug/g dry wt	<0.2 <MDL	<0.2 <MDL	<0.2 <MDL	<0.2 <MDL	<0.2	0.1	12	1	3	34	4
Cadmium	ug/g dry wt	51000	53000	57000	68000	28000	58500	no value	58,000 OTF85 not in Table **	30,000 typical value - not req'd	no value	
Cobalt	ug/g dry wt	<1.2 <MDL	<1.2 <MDL	<1.2 <MDL	<1.2 <MDL	0.97	0.61	40	21	25	no value	
Chromium	ug/g dry wt	4.9	5.1	6.7	2.6	9	2.2	750 **	71	50	no value	
Copper	ug/g dry wt	131	139	159	120	120	101	85	85	60	1700	380
Iron	ug/g dry wt	409	474	465	374	500	3.1	no value	35,000 OTF85 not in Table **	no value		
Lead	ug/g dry wt	8.1 T	5.8 T	3.5 T	<1.0 <MDL	8	980	200	120 OTF85 not in Table **	150 typical value - not req'd	no value	
Magnesium	ug/g dry wt	850	890	970	1020	680	3.1	no value	20,000 OTF85 not in Table **	3000	no value	
Manganese	ug/g dry wt	27	29	33	35	64	1.4	40	2.5	60	420	80
Molybdenum	ug/g dry wt	2.3 T	1.9 T	0.4 T	3.4 T	1.37	1.4	150	43	no value	no value	
Nickel	ug/g dry wt	3.6 T	<1.2 <MDL	<1.2 <MDL	3.2 T	3.9	2.5	no value	6500 OTF85 not in Table **	2000 typical value - not req'd	no value	
Potassium	ug/g dry wt	250	240	230	230	190	141	20	0.42	no value	no value	
Silver	ug/g dry wt	1.2 T	<0.2 <MDL	0.5 T	<0.2 <MDL	na	831	no value	910 OTF85 not in Table **	no value	no value	
Sodium	ug/g dry wt	900	920	920	1100	1200		no value	78 OTF85 not in Table **	no value	no value	
Strontium	ug/g dry wt	49	53	46	52	35		no value	5200 OTF85 not in Table **	no value	no value	
Titanium	ug/g dry wt	19	19	16	19	30		200	160	500	4200	840
Vanadium	ug/g dry wt	4.0	3.3	4.2	4.4	6	53	600				
Zinc	ug/g dry wt	65	67	81	51	76						
Nitrogen, total	mg/g dry wt	2.5	2.2	1.8	2.2	2	1.5	no value	no value	6 typical value - not req'd	no value	
Phosphorus, total	mg/g dry wt	0.48	0.50	0.48	0.50	0.34	0.32	no value	no value	2.5 typical value - not req'd	no value	
Carbon, total organic	% dry wt	26	26	26	25	na	36	no value	no value	no value	no value	
Carbon, total inorganic	% dry wt	1.5	1.5	1.6	1.9	na		no value	no value	no value	no value	
Chloride, water extractable	ug/g dry wt	130	130	140	140	na	328	no value	330	no value	no value	
Sulphate, water extractable	ug/g dry wt						786	no value	no value	no value	no value	
Total coliform	cfu/g dry wt	1.37E+07	1.20E+07	6.70E+06	2.60E+07	na		no value	no value	no value	no value	
Total coliform background	cfu/g dry wt	2.80E+07	2.30E+07	2.80E+07	3.20E+07	na		no value	no value	no value	no value	
Fecal streptococci	cfu/g dry wt	2E+04	2E+04	1E+04	3E+04	na		no value	no value	no value	no value	
E. Coli *	cfu/g dry wt	3.0E+05 *	4.70E+05 *	2.60E+05 *	5.00E+05 *	na		no value	no value	no value	no value	
Pseudomonas aeruginosa	cfu/g dry wt	45	23	93	6200	na		no value	no value	no value	no value	

T = measurable trace amount

MDL = method detection limit

na = not available

NOTE: LSB data for some tests was reported as wet weight. Results in this table are converted to dry weight using % solids.

NOTE: LSB data for microbiology tests was reported as cfu/100g. Results converted to cfu/g to compare with U.S. EPA guidelines

* U.S. EPA Class B fecal coliform guideline for animal food producing, horticulture, landfill, and animal grazing, crop harvesting after certain period of time = 2.0×10^6

** These are Typical Range values Ontario soils but are not included in Table F, as these non-hazardous elements are high in soils naturally. Note that the value given for Ca and Mg could be much higher in soils derived from limestone

*** Table A value for hexavalent chromium is 8 ug/g. Since PFB total Cr values are < 8 ug/g, by definition hexavalent Cr values are less than guidelines

TABLE 3. SOUND SORB - OSHAWA GUN AND SKEET CLUB BERM (Sampled Nov. 29/01)

Parameter	Units of Measurement	Core #1 Backlog Soil 0 - 10 cm quaffer depth	Core #1 Backlog Soil 42-50 cm quaffer depth	Core #2 Sound Soil core 0-10 cm quaffer depth	Core #2 Sound Soil core 45-55 cm quaffer depth	Core#2 Sound Soil core value 80-100 cm quaffer depth	Core#3 Sound Soil core value 0-10 cm quaffer depth	Core #3 Sound Soil 24 cm quaffer depth	Table A Contaminated Site criteria for residential/ residential land use predictor groundwater	Table F Typical Ontario Range of Background Soil Concentrations	Compost Guidelines
Solids	%			56	40	50	50	50			
Total ash	%			80	70	75	68	96			
Loss-on-ignition	%	7.2	7.2	20	30	25	32	2			
pH				8.2	8.4	8.5	8.2	8.4			
Arsenic	ug/g dry wt	2.2	1.8	1.1	1.6	0.92	1.4	1.2	20	17	10
Selenium	ug/g dry wt	0.2 <MDL	0.2 <MDL	0.13	0.11	0.10	0.070	0.044	10	1.9	2
Mercury	ug/g dry wt	0.03 T	0.02 T	0.05 T	0.05 T	0.04 T	0.04 T	0.01 <MDL	10	0.23	0.15
Cyanide (total)	ug/g dry wt	0.67 T	0.26 T	IS	7.6	0.26	IS	8.8	no value	no value	no value
Cyanide (free)	ug/g dry wt	na	na	na	0.14	0.06	na	0.40	100	0.12	no value
Aluminum	ug/g dry wt	6600	6800	4571	3670	4312	3866	6053	750	30,000	OTRSH not in Table --
Barium	ug/g dry wt	34	27	38	35	32	41	30	750	12	no value
Beryllium	ug/g dry wt	<0.5 <MDL	<0.5 <MDL	<0.5 <MDL	<0.5 <MDL	<0.5 <MDL	<0.5 <MDL	<0.5 <MDL	1.2	1.2	no value
Cadmium	ug/g dry wt	0.4 T	0.4 T	<0.5 <MDL	<0.75 <MDL	<0.6 <MDL	1 T	0.4 T	12	1	3
Calcium	ug/g dry wt	9500	3500	100000	61000	60000	58000	64000	no value	58,000	OTRSH not in Table --
Cobalt	ug/g dry wt	3.4	2.7	<2.7 <MDL	<3.8 <MDL	<3.0 <MDL	<3.0 <MDL	3.8 T	40	21	25
Chromium	ug/g dry wt	10	9	12	10	10	13	13	750	71	50
Copper	ug/g dry wt	5	3	70	80	73	58	4.4 T	225	85	60
Iron	ug/g dry wt	13000	11000	4700	3100	2900	4400	8700	no value	35,000	OTRSH not in Table --
Lead	ug/g dry wt	22	6	8.9 T	30 T	17 T	25 T	9.3 T	200	120	no value
Magnesium	ug/g dry wt	2000	1600	3100	1700	2900	2400	3200	no value	20,000	OTRSH not in Table --
Manganese	ug/g dry wt	340	280	148	139	86	159	255	no value	2200	OTRSH not in Table --
Molybdenum	ug/g dry wt	<0.5 <MDL	<0.5 <MDL	<1.1 <MDL	<1.5 <MDL	1.6 T	<1.2 <MDL	<0.7 <MDL	46	2.5	no value
Nickel	ug/g dry wt	6.5	5.4	6.3 T	8.8 T	4 T	6 T	77	150	4.3	60
Potassium	ug/g dry wt	510	490	IS	1500	2500 T	IS	2100	no value	6500	OTRSH not in Table --
Silver	ug/g dry wt	ug/g dry wt	140	<0.2 <MDL	<0.2 <MDL	<0.2 <MDL	<0.2 <MDL	<0.2 <MDL	20	0.42	2000 not required
Solvent	ug/g dry wt	140	110	118	61	540	74	530	no value	910	OTRSH not in Table --
Siliconum	ug/g dry wt	20	11	118	193	62	74	95	no value	78	OTRSH not in Table --
Titanium	ug/g dry wt	550	600	793	124	144	162	666	no value	5200	OTRSH not in Table --
Vanadium	ug/g dry wt	25	21	8	6	7	8	16	200	91	no value
Zinc	ug/g dry wt	44	28	61	55	56	102	19	600	160	500
Nitrogen, total	mg/g dry wt	1.6	0.6	4.1	2.6	3.6	6.3	0.8	no value	no value	6 not required
Phosphorus, total	mg/g dry wt	0.92	0.6	0.6	0.60	0.56	0.98	0.62	no value	no value	2.5 not required
Carbon, total organic	% dry wt	2	0.7 T	IS	8.4	6.9	IS	6.1	no value	no value	no value
Carbon, total inorganic	% dry wt	0.16	0.01 T	IS	2.7	2.8	IS	2.9	no value	no value	no value
Sulphur, total	% dry wt	0.023	0.01	IS	0.1	0.059	IS	0.14	no value	no value	no value
Chloride, water extractable	ug/g dry wt	2.6	1 T	IS	470	880	IS	840	no value	330	no value
Sulphate, water extractable	ug/g dry wt	13	18	IS	540	400	IS	530	no value	330	no value
Total coliform	cfu/g	1.00E+02 <=>	1.00E+02 <=>	1.00E+03	5.80E+03	1.20E+03	3.60E+04	IS	no value	no value	no value
Total coliform background	cfu/g	2.00E+02 <=>	1.00E+02 <=>	2.00E+04 >	2.00E+04 >	2.00E+04 >	2.00E+05 >	IS	no value	no value	no value
Fecal streptococci	cfu/g	1.00E+01 <	1.00E+01 <	1.00E+01 <	1.00E+01 <	1.00E+01 <	1.00E+01 <	IS	no value	no value	no value
E. Coli *	cfu/g	1.00E+01 <	1.00E+01 <	1.00E+01 <	1.00E+01 <	1.00E+01 <	1.00E+02 <=>	IS	no value	no value	no value
<i>Pseudomonas aeruginosa</i>	cfu/g	1.00E+01 <	1.00E+01 <	1.00E+01 <	1.00E+01 <	1.00E+01 <	1.00E+01 <	IS	no value	no value	no value

IS = insufficient sample

< T = measurable trace amount, interpret with caution

<=> = approximate result

MDU = random detection limit

NOTE: LSI data for some tests was reported as wet weight. Results in this table are converted to dry weight using % solids.

NOTE: LSI data for microbiology tests was reported as cfu/100g. Results converted to cfu/g to compare with U.S. EPA guidelines

U.S. EPA Class A fecal coliform guideline for animal food production, horticulture, landfill, and animal grazing, crop harvesting, no waiting period restriction = < 1000 cfu/g

* These are Typical Range values Ontario soils but are not included in Table F, as these non-hazardous elements are high in soils naturally. Note that the value given for Ca and Mg could be much higher in soils derived from limestone.

TABLE 4. SOUND SORB - OSHAWA GUN AND SKET CLUB BERM (Sampled Nov. 29/01)

Parameter	Units of Measurement	Core #1 Control Soil 0 - 10 cm depth	Core #1 result value 42 cm qualifier depth	Core #2 Sound Soil 10 cm depth	Core #2 result value 45 cm qualifier depth	Core #2 Sound Soil 80 cm depth	Core #3 Sound Soil 10 cm depth	Core #3 result value 24 cm depth*	Table A Contaminated Site Criteria for recreational/ residential land use possible groundwater	Table F Typical Ontario Range of Background Soil Concentrations
Volatiles Organics										
dichloromethane	ng/g dry wt		20 < MDL		20 < MDL	20 < MDL		20 < MDL	1100	3
trans-1,2-dichloroethane	ng/g dry wt		20 < MDL		20 < MDL	20 < MDL		20 < MDL	4100	3
1,1-dichloroethane	ng/g dry wt		20 < MDL		20 < MDL	20 < MDL		20 < MDL	3000	2
chloroform	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	130	6
1,1,1-trichloroethane	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	2500	8
benzene	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	200	2
carbon tetrachloride	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	100	2
bromodichloromethane	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	120	na
bromochloroethane	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	1100	4
toluene	ng/g dry wt		10 < MDL		10 < MDL	140 T		33 T	2100	2
1,1,2-trichloroethane	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	280	2
trichloroethene	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	450	2
dimethoxydimethane	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	90	3
chlorobenzene	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	2400	2
ethylbenzene	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	280	2
bromodorm	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	110	2
m and p-xylene	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	25000	total xylene below
o-xylene	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	25000	total xylene below
total xylenes	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	30000	2
1,3-dichlorobenzene	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	320	2
1,4-dichlorobenzene	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL	880	2
1,2-dichlorobenzene	ng/g dry wt		10 < MDL		10 < MDL	10 < MDL		10 < MDL		2
total petroleum distillates	ng/g dry wt		no volatile petroleum distillates		no volatile petroleum distillates	no volatile petroleum distillates		no volatile petroleum distillates		
Polycyclic Aromatic Hydrocarbons (PAH)										
naphthalene	ng/g dry wt					40 T			4600	50
acenaphthylene	ng/g dry wt					20 < MDL			100000	80
acenaphthene	ng/g dry wt					20 < MDL			15000	70
fluorene	ng/g dry wt					60 T			340000	120
phenanthrene	ng/g dry wt					220			40000	690
anthracene	ng/g dry wt					20 < MDL			28000	160
fluoranthene	ng/g dry wt					250			40000	1100
pyrene	ng/g dry wt					340			250000	1000
benzo[a]anthracene	ng/g dry wt					100			6500	740
chrysene	ng/g dry wt					100			12000	690
benzo[k]fluoranthene	ng/g dry wt					100			12000	470
benzo[a]pyrene	ng/g dry wt					40 T			12000	480
indeno[1,2,3-cd]pyrene	ng/g dry wt					80 T			1200	490
benz[e]pyrene	ng/g dry wt					40 < MDL			12000	380
dibenz[a,h]anthracene	ng/g dry wt					80 < MDL			1200	160
benz[ghi]perylene	ng/g dry wt					80 T			40000	680

TABLE 5. ATLANTIC PACKAGING PAPER FIBRE SLUDGE AND SOUND-SORB BERM, OSGS.

Parameter	Units of Measurement	Congruent Toxic Equivalent Factor	Atlantic PFB Sample 1	Value	Qualifier	Congruent Toxic Equivalent (TEQ)	OSGS Sound Sorb berm sample 40 cm	Value	Qualifier	Congruent Toxic Equivalent (TEQ)	OSGS Background Soil Control 42 cm	Value	Qualifier	Congruent Toxic Equivalent (TEQ)	1998 MOE Lab analysis of Atlantic of Packaging Sludge	2000 Atlantic Annual Report PFB pg/TEQ/g	Table A Contaminated site criteria for recreational/residential land use probable groundwater	Table F Typical Ontario Range of Background Soil Concentrations	Biocriteria Guidelines Maximum Concentration in PFB
Dioxins/Furans	2378-tetrachlorofuran	pg/g dry wt	0.1	4		0.4	2.9			0.29	0.8 <			0.08					
	2378-tetrachlorodioxin	pg/g dry wt	1	1 <		0.5	1 <			0.5	0.6 <			0.6					
	12378-pentachlorofuran	pg/g dry wt	0.05	1 <		0.025	1 <			0.025	0.5 <			0.025					
	23478-pentachlorofuran	pg/g dry wt	0.5	1 <		0.25	1 <			0.25	0.4 <			0.2					
	12378-pentachlorodioxin	pg/g dry wt	0.5	1 <		0.25	1 <			0.25	0.5 <			0.25					
	123478-hexachlorofuran	pg/g dry wt	0.1	2 <		0.05	1 <			0.05	0.9 <			0.09					
	1234678-hexachlorofuran	pg/g dry wt	0.1	2 <		0.1	1 <			0.05	0.9 <			0.05					
	234678-hexachlorofuran	pg/g dry wt	0.1	2 <		0.1	2 <			0.1	0.5 <			0.05					
	123789-hexachlorofuran	pg/g dry wt	0.1	2 <		0.1	2 <			0.1	0.4 <			0.04					
	123678-hexachlorodioxin	pg/g dry wt	0.1	2 <		0.1	2 <			0.1	0.4 <			0.04					
	123789-hexachlorodioxin	pg/g dry wt	0.1	2 <		0.1	2 <			0.1	0.4 <			0.04					
	1234678-heptachlorofuran	pg/g dry wt	0.01	14		0.14	5.3			0.053	1.7			0.017					
	1234789-heptachlorofuran	pg/g dry wt	0.01	2 <		0.01	2 <			0.01	0.5 <			0.005					
1234678-heptachlorodioxin	pg/g dry wt	0.01	29		0.29	30			0.3	1 <			0.01						
Octachlorodioxin	pg/g dry wt	0.001	470		0.47	560			0.56	4.1			0.0041						
Octachlorofuran	pg/g dry wt	0.001	170		0.17	24			0.024	3.4			0.0034						
						3.16			2.81				1.55	2.00	1.6	1000	7	100	
Note: For congeners where concentration is less than the detection limit, half of the detection limit concentration is assumed for TEQ calculation.																			
acrylamide monomer	ng/g dry wt		9				Berm 0 - 10 cm Berm 45-65 cm Berm 80-100 cm Berm 0-10 cm Berm 24 cm			0.36 <0.08 <0.06 <0.06 <0.03									
Chlorophenols																			
2,3,4,5-tetrachlorophenol	ug/g dry wt		na				na			na	na			na	<0.01		na	na	
2,3,5,6-tetrachlorophenol	ug/g dry wt		na				na			na	na			na	<0.005		na	na	
2,4,5-trichlorophenol	ug/g dry wt		na				na			na	na			na	<0.02		3.2	0.1	
2,4,6-trichlorophenol	ug/g dry wt		na				na			na	na			na	<0.01		0.66	0.1	
pentachlorophenol	ug/g dry wt		na				na			na	na			na	0.015-1		5	0.1	
Nonylphenol ethoxylates																			
nonyl phenol ethoxylates-low molecular wt			na				na				na				< 2 ng/g		na	na	
nonyl phenol ethoxylates-high molecular wt			na				na				na				< 2 ng/g		na	na	
Polychlorinated Biphenyls	ug/g dry wt		na				na				na						5	0.3	
Total PCBs			na				na				na								
Petroleum Hydrocarbons C < 16	ug/g dry wt		na				na				na								
C 16 - 50																			
Total Petroleum Hydrocarbons	ug/g dry wt						3400 at 80 cm depth										100 1000 1100	no value* no value*	

As a result of the complexity of testing for organics, not all samples of Atlantic PFB and Sound-Sorb were tested
* No Table F, OTR value derived for petroleum hydrocarbons due to analytical interference by natural organic compounds



